NUCLEONICS

A McGRAW-HILL PUBLICATION ★ SEVENTY-FIVE CENTS

March 1954

Photomultipliers

Two inch diameter

Five inch diameter

Sixteen inch diameter

Two Years Ago	Last Year	Today

Crystals

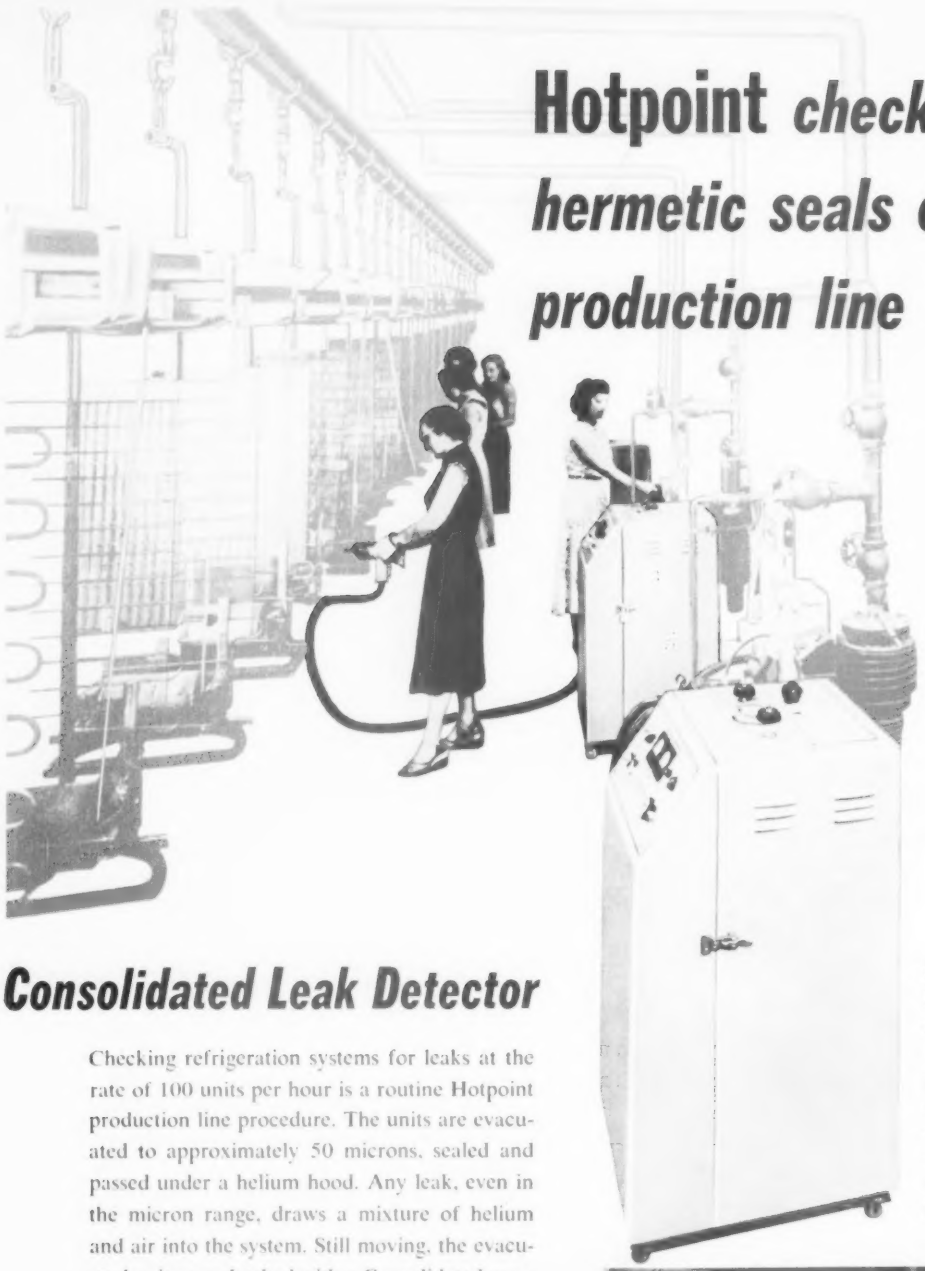
Two inch diameter

Five inch diameter

Seven inch diameter

Scintillation Counting Today **(page 13)**

Hotpoint *checks hermetic seals on moving production line*



Consolidated Leak Detector

Checking refrigeration systems for leaks at the rate of 100 units per hour is a routine Hotpoint production line procedure. The units are evacuated to approximately 50 microns, sealed and passed under a helium hood. Any leak, even in the micron range, draws a mixture of helium and air into the system. Still moving, the evacuated units are checked with a Consolidated mass spectrometer-type leak detector. The slightest trace of helium sounds an audible alarm and the faulty unit is pulled off the line. These mobile, highly sensitive leak detectors are adaptable to a wide range of operations for production line control of both vacuum and pressure systems.

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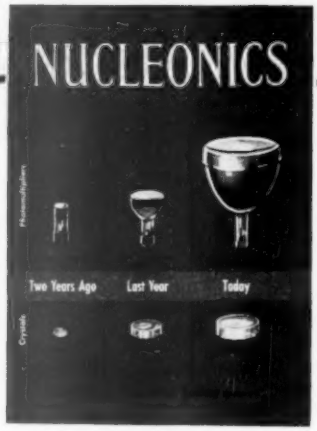

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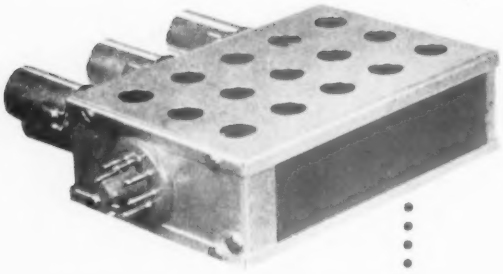
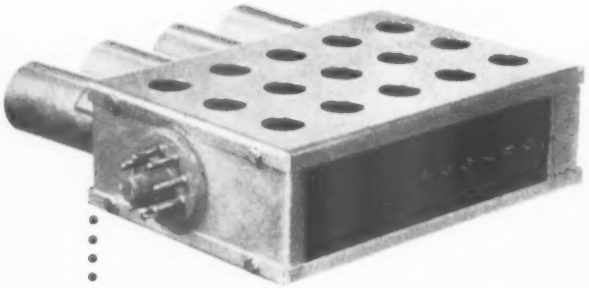


FOR BINARY COUNTING



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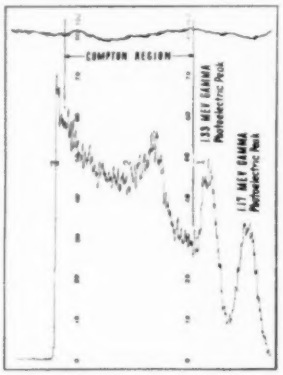

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• May be used with the RIDL AUTOMATIC SAMPLE CHANGER that changes samples when the sweep circuit resets.

• Each of the components may be operated *separately*. Truly a versatile instrument for your operation.

• Channel level and counting rate may be *instantly* read off 4½ inch panel meters located on the ELECTRONIC SWEEP AND COUNT RATE COMPUTER.

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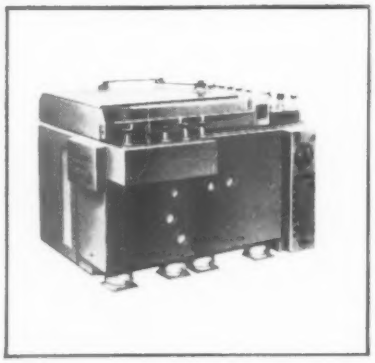

14

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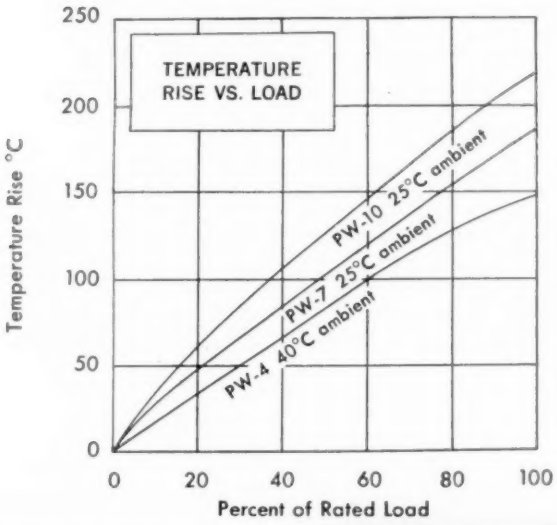
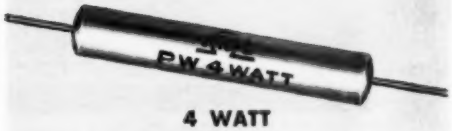
IRC's new power wire wounds are lower cost per watt than any other power type. At 4, 7 and 10 watts, they offer savings of several cents each in any application requiring compact, low cost, efficient power resistors. Types PW-4, PW-7 and PW-10 resistors assure safe operation in circuits where stability and low wattage dissipation are needed.





4 WATT

Type PW-4 allows safe operation with hot-spot temperatures up to 165°C. Fully insulated housing will not burn or support combustion.

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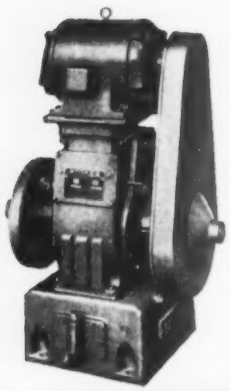
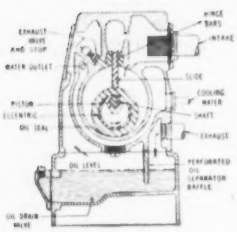
Cut Costs...Boost Efficiency...with Stokes High Vacuum Pumps



At left is the new Model G Stokes High Vacuum Pump. Basically, and in outward appearance, the new model is the same simple, efficient, compact and reliable unit as its widely used predecessor, Model F. Five major engineering improvements are incorporated in the new model: 1) a new mechanical face-seal minimizes routine maintenance and reduces to a minimum the possibility of oil leakage at the shaft; 2) new exhaust valve-stops permit use of these pumps in an exceptionally broad range of applications, including rapid cycling evacuation of large-volume systems; 3) a new intake screen filter prevents damage by dirt, scale, and other solids sometimes present in the system; 4) a new oil filter in the line to the shaft seal affords special protection to the bearings at these points; 5) a new solenoid valve in the oil supply line automatically prevents oil-flooding of the pump in the event of power failure.



The operating principles of the Stokes High Vacuum Pump are simple. Rotation of the Stokes Pump is indicated in cross-section view at left: Air enters the increasing space at right of piston, while air trapped in the decreasing space at left of piston is compressed. As piston nears top of stroke, pressure of the trapped air opens the feather-type discharge valve against atmospheric pressure, and the air is forced out of the cylinder. As piston passes through its top position, the suction port is momentarily closed by piston. Air then present in cylinder is trapped, a new cycle begins.

A completely revised brochure on Stokes High Vacuum Pumps is now available, free, upon request. It explains, and shows, how Stokes Pumps combine simplicity of design, high volumetric efficiency and lowest operating costs to provide reliable, continuous service for all kinds of high vacuum processing equipment. Examples of typical vacuum systems using Stokes Pumps are cited and typical problems in pump selection and their solution are provided. Also described is the complete line of Stokes High Vacuum Processing Equipment and the new Stokes Experimental and Applications Laboratory in Philadelphia, Penna.

The new Stokes Vacuum Calculator for rapid slide-rule vacuum calculations, including a standard ABCD log scale, is now available, free, upon request. It has proved to be of tremendous value to those engaged in vacuum research and processing. Simplifies determination of pump capacity required for given volume in given time or given volume to specified vacuum with user's present equipment. Numerous tables on reverse face provide useful vacuum reference data.

Send for copy of a new handbook "How to Care for Your Vacuum Pump." (Bulletin No. 755). Contains many valuable suggestions about installation, starting, servicing, trouble-shooting; and helpful "Do's" and "Dont's" on vacuum pumps and vacuum pumping systems.

Simplicity and sturdy construction, accessibility, high volumetric efficiency, low power consumption, and effective cooling are distinctive features of Stokes High Vacuum Pumps.

Better blank-off pressures and quieter operation are assured with a completely new, longer lasting exhaust valve assembly. Intake ports are open during the entire intake cycle; there is no slide-valve shut-off.

Lubrication is completely automatic. There are no oil shut-off valves and adjustments. Horizontal vacuum intake permits trapping of harmful dirt and scale. Vacuum-tight rotary seals eliminate the need for shaft packing and constant adjustment. Easy access is provided to the valve assembly and other parts requiring periodic examination.

Stokes High Vacuum Pumps are available in capacities from 15 to 500 cfm. Where necessary, oil purification units — to assure continuous supply of clean, water-free oil — can also be furnished.

Wherever hard, continuous service is required to meet today's exacting high vacuum requirements, Stokes High Vacuum Pumps prove a profitable investment.

Consult with Stokes on the application of high vacuum to vacuum melting, casting, sintering, heat-treating, and degassing; to vacuum metallizing, gaseous diffusion, emission equipment and to other purposes for which vacuum deserves study.

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STOKES

STOKES MAKES: High Vacuum Equipment, Vacuum Pumps and Gages/Industrial Tabletting, Powder Metal and Plastics Molding Presses/Pharmaceutical Equipment

Advances in Applied Radiation

DEVELOPMENTS in the FIELD OF APPLIED RADIATION ENERGY, its APPLICATIONS and the APPARATUS USED TO PRODUCE IT

This is the first of a series of informal reports designed to acquaint industry with High Voltage Engineering Corporation and with the interesting possibilities of the fields where our products and services are used or promise to be useful. Broadly, we define this field as that of applied radiation energy.

Progress Report: Radiation Sterilization

The level of interest in the application of radiation sterilization to drugs and surgical supplies is high and it seems likely that 1954 will see the first commercially marketed products processed with radiation energy. Reductions that have been made in the capital cost of both production and research type equipment should hasten commercial use of this sterilization method.

It is now well established that complete bacterial sterility can be achieved by using radiation, and the necessary radiation dosage levels are known. It will probably be some time, however, before extensive use of radiation sterilization is made in the food industry. The possibilities of sterilizing foods without any significant heat rise and of treatment in the final container are attractive, but there is a major problem to be solved before commercial applications become feasible.

Side effects are produced in most foods when treated with radiation. These side effects usually manifest themselves as a change in taste or odor, and sometimes as a change in color as well. Little is known about the causes of these changes. Fundamental research now under way both in industry and in government is specifically directed toward learning more about the nature of these effects and toward means of preventing them. The use of additives as free radical acceptors, irradiation in the frozen state, irradiation in an inert or oxygen-free atmosphere, and the careful control of dosage all show promise. While really extensive use of radiation sterilization in the food industry must await the solution of these fundamental problems, the surface treatment of some food products like meats, frankfurts, and possibly cheese may soon be useful in lengthening shelf-life.

Los Angeles Tumor Institute

The newest U. S. installation for the supervoltage treatment of cancer is at the Los Angeles Tumor Institute in California and is under the direction of Dr. Hugh F. Hare, formerly associated with the Lahey Clinic in Boston, and a pioneer in the use of 2-million-volt x-rays in cancer therapy. His Van de Graaff is the second HIGH VOLTAGE *therapy installation on the West Coast. The other opened early this year and is directed by Dr. S. T. Cantril at the Tumor Clinic of the Swedish Hospital in Seattle.*

About HIGH VOLTAGE

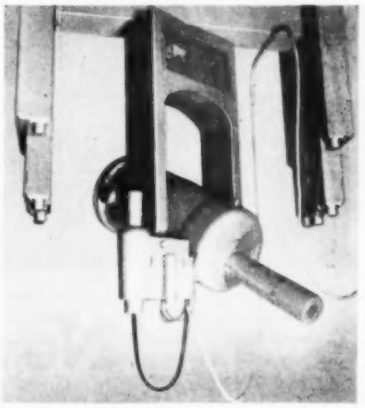
When produced at high energies, fundamental radiations or particles, such as x-rays, electrons, or neutrons, can penetrate matter in varying degrees. In doing so, they characteristically produce ions by dissociating molecular and atomic structures and are, therefore, termed ionizing radiations, as opposed to heat radiations, for instance. HIGH VOLTAGE is concerned mainly with the applications of ionizing radiations which can be produced by means of the particle accelerators we manufacture.

HIGH VOLTAGE ENGINEERING CORPORATION was formed in 1946 to exploit the usefulness of what is now the most widely used type of particle accelerator, the Van de Graaff, in producing radiations for cancer therapy, nuclear research, and industrial radiography. Since then, the company has produced nearly half of the Van de Graaffs now in use in this country.

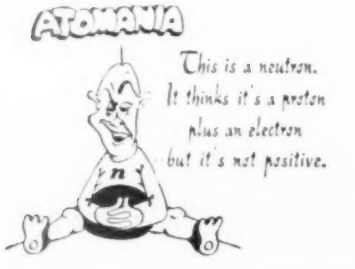
Industrial applications for the ionizing radiations from these accelerators already touch pharmaceutical and surgical-supply manufacture and have broad possibilities in chemical processing and control, in geophysical exploration, and in the food industry.

Van de Graaff accelerators are produced by the company in a variety of designs covering the energy range from 0.5 to 6.0 million volts. Recently the company has been investigating other types of particle accelerators as well and is currently constructing, in cooperation with Stanford University, a 50-million-volt microwave linear accelerator for the Argonne Cancer Research Hospital in Chicago.

Big Jobs for X-rays



A two-million-volt Van de Graaff x-ray generator, the first of its type to be used in private industry, has been installed at the new Wilkes-Barre plant of Foster Wheeler Corporation. This supervoltage equipment, capable of showing clear detail in steel sections up to twelve inches thick, was built by HIGH VOLTAGE to meet Foster Wheeler's exacting requirements for precision radiographic inspection of heavy steel sections and weldments. Supported in a rotatable mount on a bridge crane, the huge generator can direct its x-rays at the work from any angle. This Van de Graaff will permit inspection in considerably less time than conventional apparatus. The resulting x-ray films will become part of the fabrication record of the heavy equipment to be built at this plant for oil refineries, steam power plants, and process industries.



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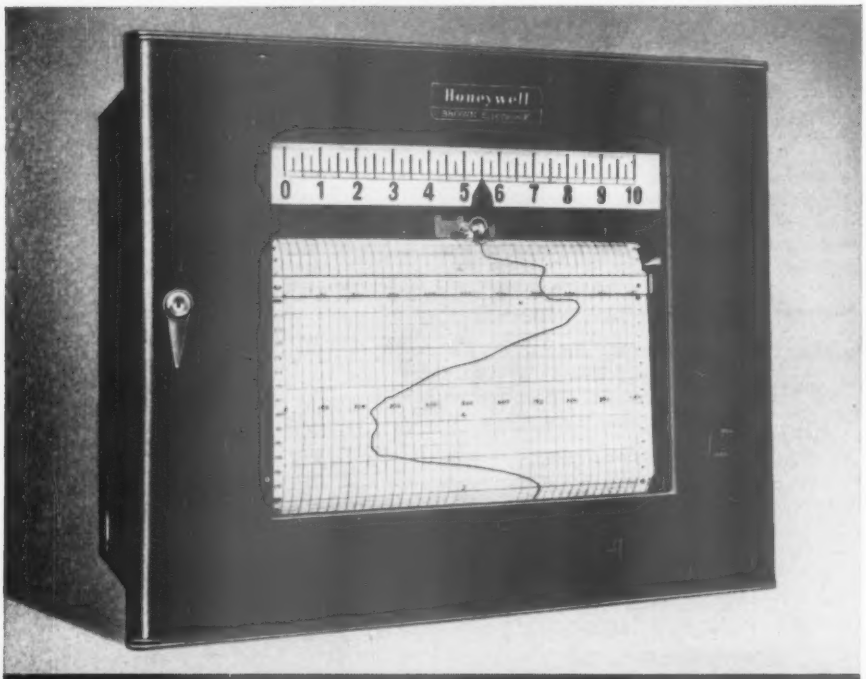

approximate maximum sensitivities

AMPLIFIER	SPAN	VOLTAGE SENSITIVITY	CURRENT SENSITIVITY
3x	2mv	1 x 10^{-6} volts	8 x 10^{-12} amp
1x	10mv	3 x 10^{-6} volts	2.5 x 10^{-11} amp

New *ElectroniK* recorder *for high impedance circuits*

A NEW MODEL of the *ElectroniK* instrument now makes it possible to record data from high impedance sources without resorting to external pre-amplifiers. It can measure voltages originating in sources with impedances ranging from 0 to 50,000 ohms without appreciable change in sensitivity, damping or speed.

Because of its high input impedance, the instrument can be applied to voltage measurements with negligible loading effect on the source. It is also applicable to current measurements in conjunction with photocells, spectographs and similar devices.

The recorder is supplied with pen speed of 24, 12, 4 1/2 or 2 seconds, for spans down to 2 mv. The amplifier can be used separately in many high impedance servo systems.

Excellent stray rejection, meeting the most stringent specifications, is incorporated in the new circuit. Stray a-c voltages, equal to full scale span for the 2-second model and up to 10 times the span for the 24-second model, are rejected with no appreciable loss in instrument sensitivity.

Your nearby Honeywell sales engineer will be glad to discuss your applications . . . and he's as near as your phone.

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● **REFERENCE DATA: Write for Instrumentation Data Sheet No. 10.0-14.**

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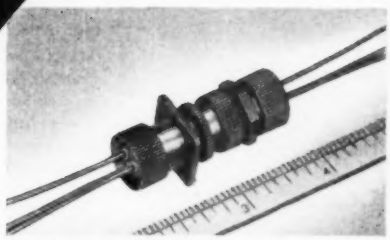
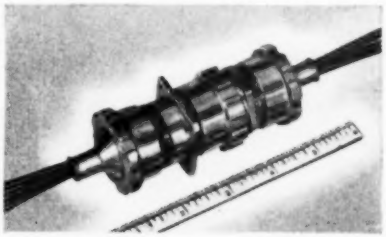
Extreme Temperature and Altitude Problems Solved by New Modifiable Titeflex Connector

We have the experience to solve most complex connector problems involving extreme altitudes, temperatures and pressures with space and weight limitations. And within standard design requirements, we can develop special-duty connectors as a part of complete wiring systems.



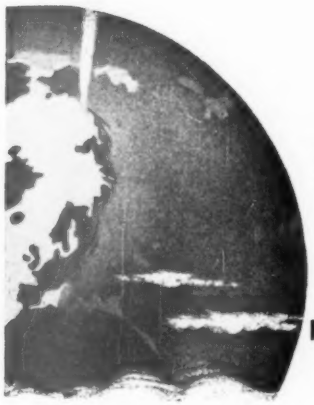
INSTRUMENTATION Connector —07. For moisture and corrosion resistance, temperature ranges of −65°F. to +400°F. Made of Teflon, plug and receptacle mated weigh only ⅔ oz. Length 2". Insulation properties will permit 3500 volts at sea level, 1200 volts at 50,000 feet altitude. Can be made with 2 or 3 pins, current 7 amperes.



MOISTURE-PROOF and resistant to synthetic lubricants. For extreme temperature changes in ranges of −65°F. to +400°F., high altitudes up to 65,000 feet. Resists salt spray, corrosion, vibration. This Titeflex Connector is radio shielded, has positive retention of pins and sockets. 5" in length. Mates with connectors that conform to MIL-C-5015.

CUSTOM WIRING SYSTEMS—For accessory, instrumentation and radio shielded applications. Can be furnished with Titeflex or Standard AN Connectors. Can be sheathed with one or more layers of various metal braids, fiber glass or nylon, and jacketed with silicone or various other compounds. Titeflex will be glad to design, develop and produce complete wiring systems to your specifications.

SPECIAL —07 CONNECTOR. Designed to solve your connector problems in instrumentation with a real saving in space and weight since this connector has no protuberance beyond the flange. Can be designed as an integral part of your wiring or instrument components. Available in 1, 2 or 3 pin arrangements—current 7 amperes, size 1" in length. Receptacle and plug weigh only 11 grams.



All TITEFLEX Connectors can be furnished with thermocouple pins and sockets.

WRITE TODAY for specific information—or send us your specifications. Whatever your requirements, we can usually provide the right answer. Our Engineering Staff will be glad to discuss your problem without obligation.

LET OUR FAMILY OF PRODUCTS HELP YOURS

Titeflex

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MAIL COUPON TODAY

Please send me your catalog on the Titeflex Connector.

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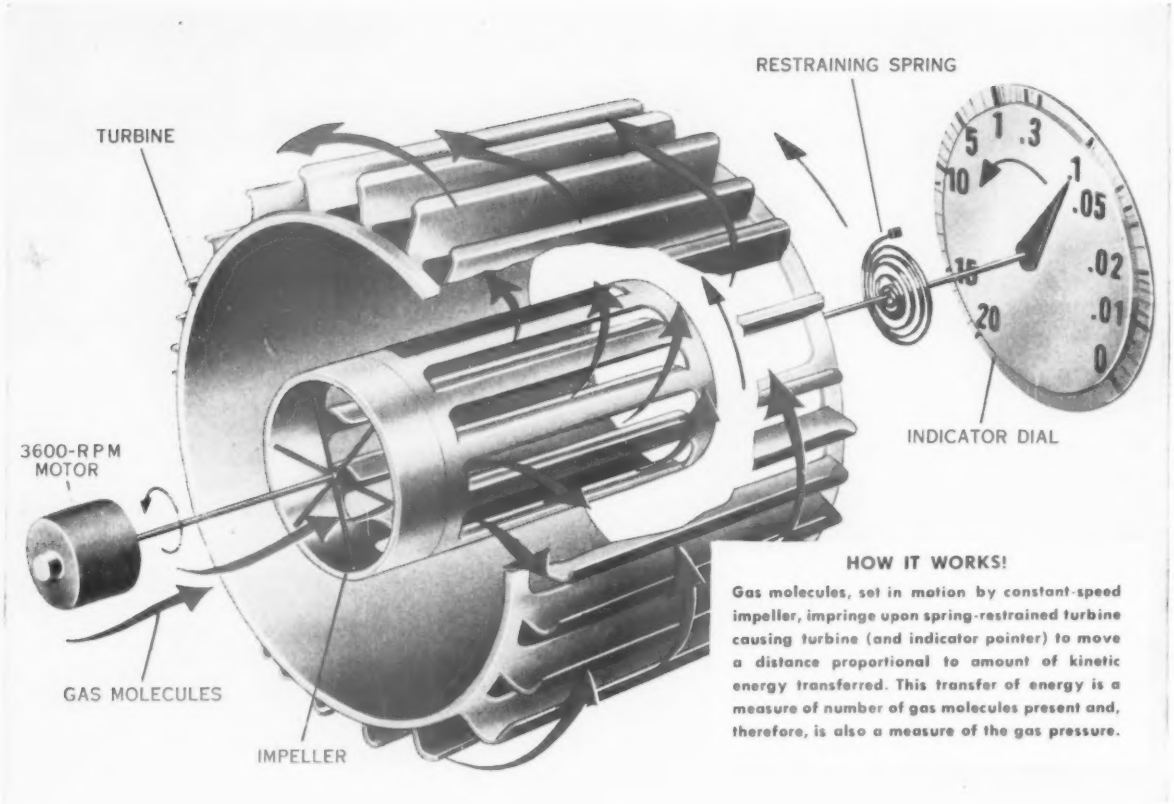

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NUCLEONICS MARCH, 1954

Jerome D. Luntz, *Editor*

The Course of Reactor Development

THE PAST TWO MONTHS have defined quite clearly the role of industry in the several areas of nuclear reactor technology. The relative rate of development of these areas is also becoming more apparent.

Four kinds of reactors are of interest:

1. Central-station power reactors
2. Small package power reactors
3. Propulsion power reactors
4. Research reactors

Five recent events provide the basis for assessing the course of reactor development:

1. Jan. 21—launching of nuclear-propelled submarine, *Nautilus*
2. Feb. 2—submission to Joint Congressional Committee on Atomic Energy of AEC's proposed "5-year program for reactor development"
3. Feb. 12—exploratory letters to industry regarding proposed invitation to bid on Army package reactor
4. Feb. 17—widely attended unclassified conference on research reactors
5. Feb. 17—President's special message to Congress on atomic energy

WHEN IN JANUARY we saw the *Nautilus* slide gracefully down Electric Boat's ways at Groton, Conn., we were stirred at the realization that this symbolized the first practical harnessing of nuclear power. Of course, the *Nautilus* means more than just a symbol. In the words of Alvin Weinberg, research director of Oak Ridge National Laboratory, "The success of the nuclear submarine power plant has resulted in the establishment of one and possibly two bona fide equipment manufacturing industries. First is the manufacture of nuclear-powered submarines; this . . . is as valid an industrial enterprise right now as is the manufacture of any other advanced naval vessel or power plant . . . "

"The second industrial equipment activity which has already stemmed from this demonstration of compactness [of nuclear fuel]," Weinberg said, "is the manufacture of power package reactors, based on water-cooled and moderated design, for use in remote localities." Elsewhere in this issue (p. 75), there is reported the details of AEC's interest in getting competitive bids from industry on the first package reactor.

MOBILE AND PACKAGE REACTORS represent the short-term aspect of reactor work by industry. Item 2 above—the "5-year program for reactor development"—is part of the long-term picture. This program, the details of which were reported in these pages last month (NU, Feb. '54, p. 75), is designed to pursue the four most promising avenues of development. It is expected that most of this expensive groundwork will be done by the AEC national laboratories.

Item 4 on research reactors concerns an area in which industry is already at work. This was brought out at a two-day conference at Oak Ridge last month that drew representatives from 58 universities with varying degrees of interest in reactors for their campuses. Also present were men from about a half dozen companies that have a very competitive interest in building reactors for universities and other non-AEC groups.

Item 5, the President's atomic energy legislative recommendations (see p. 74), affects each of the first four items. The continued interest and the degree of interest of industry in all types of reactors depends to a considerable extent on whether the President's recommendations are approved. If Congress amends the Atomic Energy Act as requested, growth of the field in the next five years may be as follows (in terms of numbers of reactors on which construction is started):

1. Central-station power reactors—2 (excluding PWR)
2. Small package power reactors—3
3. Propulsion power reactors—3 (excluding STR and SIR)
4. Research reactors—6

Thus it appears that the basis for a healthy industry is coming into existence.

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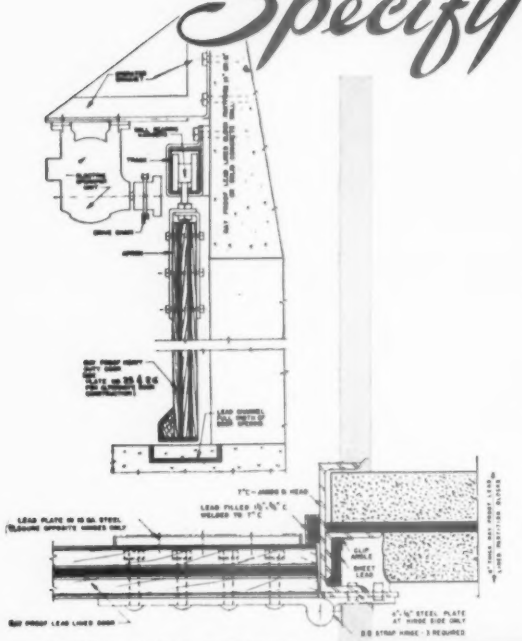

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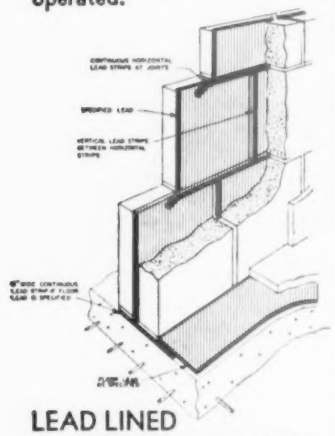

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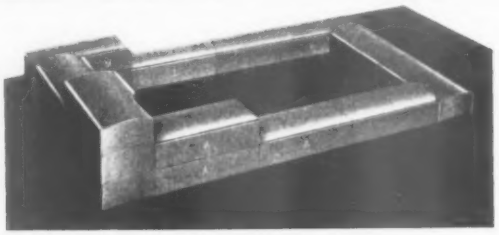

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Scintillation Counting Today

IN THE NEXT 41 pages, NUCLEONICS presents seven articles and four reports that spell out the status of scintillation counting. Comparison with the last such report (NU, Mar '52, p. 32) shows that use of this technique for detecting and measuring radiation is expanding more than rapidly.

One aspect of this expansion is shown on the cover. To meet the requirements of new applications, detector components are getting larger. But a gap exists between the growth of crystals and photomultipliers; as shown in the following pages, plastic (p. 28) and liquid (p. 44) scintillators are filling this gap and may be the ultimate solution to the need for large detectors.

Detectors are also becoming smaller (p. 14, 26), and electronic circuits less bulky, simpler, and more reliable (p. 33, 54, 55). Flexibility is a prime factor in the current expanding application of scintillation counters.

This report is based on the Fourth Scintillation Counter Symposium, held in Washington, D. C., on January 26 and 27. The editors thank H. D. LeVine, R. T. Graveson, A. H. Yoli, and H. Sadowski of the AEC New York Operations Office for their aid in reporting and summarizing many of the shorter papers.

Phosphors and photomultipliers 14

General applications 29

High energy and cosmic rays 36

Spectrometry 51

Several theories attempt to explain the mechanism of the scintillation process in crystals, liquids, and solid solutions. These are discussed here in relation to the scintillation efficiency, decay time, and energy and nature of the radiation

Recent Advances in Theory

By ROBERT K. SWANK
Argonne National Laboratory
Lemont, Illinois

THE WIDESPREAD ACCEPTANCE of scintillation counting as a standard technique for the measurement of ionizing radiations has made it imperative that a satisfactory understanding be obtained of the fundamental principles involved in the scintillation process.

It has been shown (*1*) that the energy lost by a charged particle per centimeter traveled is proportional to the square of the particle's charge and roughly inversely to the square of its velocity. For the particles and energies we will consider, the energy is almost entirely consumed in ionization and excitation of the electrons in the medium, with very little energy being consumed directly in the form of nuclear collisions or radiation. This electronic-excitation energy is rapidly degraded into heat with only a small amount, 10% or less, escaping as visible or ultraviolet radiation.

The emission observed in a scintillation nearly always corresponds to a transition from the lowest excited state to the ground state of the molecule involved. The time required for the conversion of higher excited states to the lowest excited state or to the ground state is generally much shorter than the lifetime of the lowest excited state. Therefore, the three processes, (1) excitation, (2) degradation of excess electronic energy, and (3) emission of light from the lowest excited state, may be treated in many cases as three successive stages in the production of a scintillation. The last process then corresponds exactly to the emission process in ultraviolet fluorescence. It is therefore convenient to use the concept of fluorescence quantum efficiency to denote the ratio of fluorescence photons emitted to the number of excitations in the first excited state produced by the high-energy particle.

Fluorescence Efficiency

According to this concept, the number of photons observed in a scintillation may be written as

$$N = (E/w)q \qquad (1)$$

where E is the energy of the particle, which is assumed to be entirely expended in the scintillator; w is the average energy required to produce one "fluorescence" excitation; and q is the fluorescence quantum efficiency. The scintillation efficiency is then defined as

$$N/E = q/w \qquad (1a)$$

Equations 1 and 1a are strictly valid only for high-energy electrons and for scintillators not involving an activator. Other cases can be accounted for by suitable modification of these formulas.

The fluorescence quantum efficiency, q, is related to the lifetime of the excited state. For, if the probabilities per unit time for emission and quenching are p_e and p_q, respectively, the quantum efficiency is

$$q = p_e/(p_e + p_q) \qquad (2)$$

and the lifetime of the excited state is

$$\tau = 1/(p_e + p_q) = q/p_e \qquad (3)$$

Thus, for a given emission probability, the quantum efficiency and the lifetime of the excited state are proportional.

Organic Crystals

Of those materials that scintillate without the addition of activators, the largest group is the class of organic compounds often referred to as aromatic ring compounds. These molecules all consist of one or more benzene rings, together with various nonaromatic substitutions. They all contain resonating structures, a property that is afforded in most cases by a series of alternating single and double bonds. It is the resonance of these structures that gives rise to the first excited state, from which luminescence occurs. The energy difference between the ground state and the first excited state is smaller the longer the unbroken sequence of alternating single and double bonds.

The relationship between chemical structure and scintillation efficiency has been investigated by Sangster (*2*) and others. Several general relationships have been noted:

1. The optimum scintillation efficiency is reached when the length of the resonating structure is such as to yield an emission spectrum of ~4,000 Å.
2. A high degree of symmetry in the molecule is desirable, together with the absence of steric hindrance.
3. Scintillation efficiency is reduced

TABLE 1—Efficiency of Several Scintillators

Scintillator	*Wavelength of maximum emission*	*Relative beta-ray pulse height*	*Alpha-to-beta ratio (%)*
Anthracene Crystal	4,440	100	9
Stilbene Crystal	4,100	60	9
Xylene + 5 gm/liter terphenyl + 0.01 gm/liter diphenylhexatriene	~4,500	48	9
100 gm polyvinyltoluene + 4 gm terphenyl + 0.1 gm diphenylstilbene	~3,800	48	9
NaI(Tl)	4,100	210	44
LiI(Sn)	5,300	12	~93
LiI(Eu)	~4,400	75	~95

# of Scintillation Phosphors

by halogen, carboxyl or nitro substitutions, but is enhanced by amino, hydroxyl and alkyl substitutions.

Of all the organic scintillators investigated so far, anthracene is the most efficient.

Liquid Scintillators

The difficulty of producing organic crystals of large volume and high optical quality has led to the widespread use of liquid scintillators. Although these scintillators produce smaller pulse heights than the best crystals, this limitation is more than offset by greater economy and versatility.

Our present understanding of the behavior of these scintillators is primarily due to the work of Kallmann and Furst (*3*). They have shown that the "fluorescence" excitations produced in the solvent are quickly transmitted to the solute before quenching can occur. The excitation energy, which is thus trapped and degraded by the solute, can be subsequently emitted from the solute with a high efficiency. Since the normal quenching in the solvent is bypassed, the net effect is as though the quantum efficiency of the solvent had been greatly increased so that

$$N = (E/w_0)q'$$
$$q' = (\sigma c/1 + \sigma c)(q_1/1 + mc) \quad (4)$$

where w_0 is the average energy required to produce one "fluorescence" excitation in the solvent, c is the molar concentration of the solute, σc is the ratio (probability of trapping in the solute)/(probability of quenching in the solvent), and m is the self-quenching constant of the solute.

Since the energy of the fast particle is expended almost entirely on the solvent, the parameter w_0 applies to the solvent. The "effective" quantum efficiency of the solvent is q'. It consists of two factors. The first factor, $\sigma c/(1 + \sigma c)$, is the fraction of fluorescence excitations in the solvent that is transferred to the solute. (It is assumed that the emission from the solute is negligible.) The second factor, $q_1/(1 + mc)$, is the quantum efficiency of the solute. It has a maximum value q_1 at very low concentrations, decreasing with increasing concentration. This decrease in quantum efficiency with increasing concentration, usually referred to as self-quenching, is a property of nearly all complex phosphors and is observed with both ultraviolet and particle excitation. The value of the self-quenching constant, m, is mostly a property of the solute, but also depends on the solvent, and to some extent on the mode of excitation.

Equation 4 predicts a maximum value of q', and hence of N, at $c = (\sigma m)^{-1/2}$. Kallmann has shown that an expression of the form given by Eq. 4 is in very good agreement with experimental observations of light output vs concentration of the solute.

Solid Solutions

After the report by Schorr (*4*) that scintillations had been observed in solid solutions of terphenyl in polystyrene, the question naturally arose as to whether the processes occurring in this type of scintillator could be explained in the same manner as those occurring in liquid scintillators.

Koski (*5*) observed ultraviolet luminescence from pure polystyrene and suggested that adding a fluorescent compound to polystyrene served merely to absorb the ultraviolet radiation emitted, and to reemit it at longer wavelengths. This would increase the pulse size by overcoming self-absorption and by gaining a better match to the spectral response of the photomultiplier. Since these early experiments yielded scintillation efficiencies of only 5–10% relative to anthracene, the explanation offered by Koski seemed adequate.

When the results of Pichat and Koechlin (*6*) in 1951 showed that efficiencies relative to anthracene as high as 30% could be obtained with solid solutions of tetraphenylbutadiene in polystyrene, some additional explanation seemed necessary.

These experiments were repeated and extended at Argonne National Laboratory (*7*). The high efficiencies reported by Pichat and Koechlin were confirmed, and other solid solutions were investigated having efficiencies ranging up to 48% of crystalline anthracene. Curves of pulse height vs concentration were found to be similar to those reported for liquid scintillators, except that (1) a significant

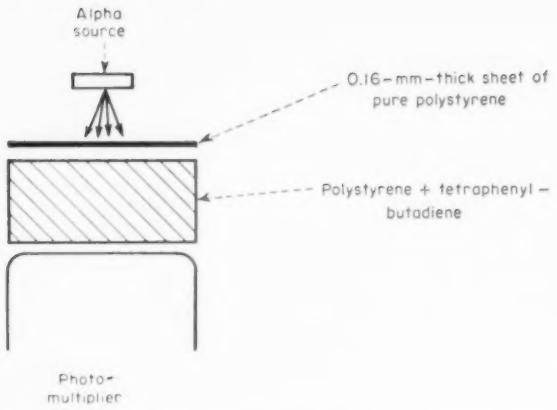

FIG. 1. Experimental arrangement for study of energy-transfer mechanism in polystyrene

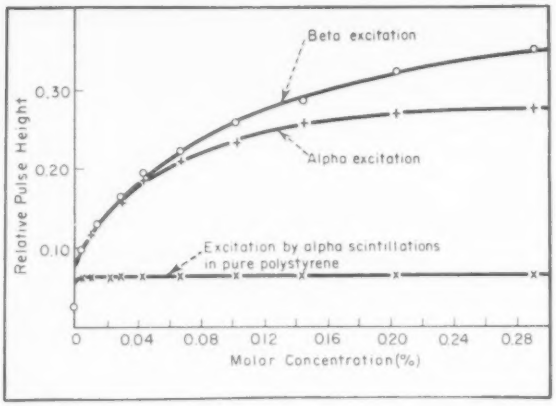

FIG. 2. Pulse height as a function of tetraphenylbutadiene concentration in polystyrene

emission was observed from the pure solvent and (2) the solute concentrations required for maximum pulse height were about tenfold higher in the case of plastics than in the case of liquids. The high efficiency, together with the fact that the radiation emitted had the characteristic spectrum of the solute, forced the conclusion that the excitation produced originally in the solvent was transferred to the solute before emission.

Studies of polystyrene. To determine whether this transfer of excitation energy was by radiation from the solvent followed by absorption in the solute, or by a nonradiative transfer mechanism, the following experiment was performed (Fig. 1).

Alpha particles are stopped in a thin sheet of pure polystyrene. Any ultraviolet emission from the sheet can be absorbed by the fluorescent compound which is dissolved in the polystyrene cylinder beneath. By removing the sheet, the alpha particles impinge directly on the cylinder of polystyrene in which the fluorescent compound is dissolved. It was determined spectrophotometrically that the thin sheet was transparent from 3,000 Å to 4,000 Å, the region in which the predominant emission from polystyrene occurs. Thus, if radiation in this wavelength region is the means by which energy is transferred from the solvent to the solute, this transfer should take place equally well whether the alpha particles are absorbed in the pure polystyrene sheet or directly in the polystyrene cylinder containing the fluorescent compound.

With tetraphenylbutadiene as the fluorescent solute, pulse heights were measured as a function of solute concentration with and without the pure polystyrene sheet in place. The resulting curves of pulse height vs concentration of tetraphenylbutadiene are shown in Fig. 2, together with a curve for direct beta excitation of the cylinder. The curves are normalized to coincide at zero concentration. A comparison of the magnitude and shape of the two curves leads to the conclusion that radiation and reabsorption account for no more than 20% of the energy transfer from solvent to solute.

A study was also made of the decay time of polystyrene with various concentrations of several activators. It was found that the decay time of polystyrene, observed to be 15 mμsec for the pure material, decreased rapidly with increasing concentrations of tetraphenylbutadiene or terphenyl, reaching a final value as low as 2.8 mμsec for a few mole percent of terphenyl. This decrease in decay time with increasing concentration of the solute is contrary to the expectations for a transfer of energy by radiation and reabsorption, unless the observed decay time of the pure material has been greatly lengthened by repeated self-absorption. Absorption measurements on the materials used indicate that such large amounts of self-absorption are unlikely.

Based on the conclusion that a nonradiative transfer of energy does exist, one can derive a formula for the pulse height as a function of concentration very similar to that derived for liquid scintillators. A term must be added to account for the small amount of fluorescence emitted by the solvent

$$N = \frac{E}{w_0}\left(\frac{\sigma c}{1+\sigma c}\right)\left(\frac{q_1}{1+mc}\right) + (\text{emission from solvent}) \quad (5)$$

Fortunately, for most of the solutes studied, the solvent fluorescence was completely absorbed by them at very low concentrations so that the expression for the pulse height above these concentrations could be expressed in terms of the absorbed and reemitted radiation

$$N = \frac{E}{w_0}\left[\left(\frac{\sigma c}{1+\sigma c}\right)\left(\frac{q_1}{1+mc}\right) + \left(\frac{q_0}{1+\sigma c}\right)\left(\frac{q_1}{1+mc}\right)\right] = \frac{E}{w_0}\left(\frac{q_0+\sigma c}{1+\sigma c}\right)\left(\frac{q_1}{1+mc}\right) \quad (6)$$

where q_0 is the quantum efficiency of the solvent. It must be divided by $(1 + \sigma c)$ to account for the quenching of this emission by the competing process of nonradiative energy transfer, and, of course, must be multiplied by the quantum efficiency of the solute since the solvent radiation is absorbed and reemitted by the solute. Agreement of Eq. 6 with experiment is seen in Fig. 3, where the solid lines are plots of Eq. 6 fitted to data.

Transfer Mechanisms

In the case of most inorganic crystal scintillators, the migration of excitation energy from the host crystal to the activator center is adequately explained by the migration of electron-hole pairs. However, the lack of photoconductivity in organic scintillators makes this mechanism seem unlikely.

A theory has been presented by Kallmann (*3*) that is based on an exchange of energy between two molecules as a result of quantum mechanical resonance. A calculation made by Harrison (*8*) indicates that this mechanism can account for the migration of energy in liquid scintillators if an interaction energy of about 40 mv can be assumed between the solvent molecules. This energy seems to agree with the observed shift in absorption and emission spectra of benzene in going from the gaseous to the liquid state.

The energy transfer mechanism in a theory presented by Förster (*9*) is described as an interaction resulting from the mutual energy of the electric dipoles of the two molecules involved Since, in this case, the transfer takes place after thermal equilibrium has been established, it is necessary that the emission spectrum of the donor molecule overlap the absorption spectrum of the acceptor molecule. The transfer probability is proportional to the oscillator strengths of the transitions and to the degree of overlap of the spectra. Experiments with plastic scintillators have shown that a good correlation exists between the above spectral requirements and the rate of rise of pulse height with concentration, as predicted by the theory.

It is possible that two different energy-transfer mechanisms may be necessary to account for the experimental observations. One transfer mechanism may account for the exchange of excitation among solvent molecules and another for the final transfer to the solute. More experimental work must be done before a positive identification can be made of the transfer mechanism.

Self-Quenching

Although much remains to be learned about the process by which energy is transferred from the solvent to the solute, causing the scintillation pulse height to increase with increasing concentration, our knowledge is even more meager concerning the self-quenching mechanism, which causes the pulse height to decrease when the concentration is raised beyond a certain optimum value. This phenomenon is characteristic of all classes of activated phosphors.

The simplest explanation of such a behavior would be that reabsorption followed by internal quenching accounted for the loss of pulse height at high concentrations. However, measurements of decay time and absorption appear to disagree with this simple explanation, in some cases at least.

Formation of double molecules, with reduced emission probability, has also been proposed. Another explanation, proposed by Franck and Livingston (*10*), would show the behavior of true quenching. This model of self-quenching is based on a combination of rapid energy transfer, together with internal quenching by the molecules. Transfer of energy would increase quenching probability provided the mean lifetime for energy transfer were smaller than the average time required for the molecule to change from a mode of vibration producing quenching to a mode unfavorable to quenching. In this case the excitation energy would effectively be shared by a number of molecules and the quenching probability would be the sum of the quenching probabilities of the several molecules. This would reduce the scintillation intensity and decay time accordingly.

Energy Dependence

The equations presented so far apply strictly only to high-energy electrons. In this case, the scintillation amplitude is strictly proportional to the energy of the particle stopped in the scintillator. For low-energy electrons and for heavy particles, the number of photons produced per unit energy expended is a function of the energy.

Although a number of investigators have contributed to our experimental knowledge of this effect, the most comprehensive data has been that of Taylor *et al.* (*11*). Their results for anthracene are illustrated in Fig. 4 where the ratio of scintillation amplitude to the particle energy is plotted against the energy for electrons, protons, deuterons, and alpha particles. The curves are normalized to 100 for high-energy electrons. It is assumed, of course, that the particle is brought to rest in the scintillator. A behavior similar to that shown in Fig. 4 seems to be characteristic of nearly all scintillators. Different scintillators will vary considerably, however, in the degree to which they exhibit this property.

A convenient measure of the degree to which any particular scintillator is affected by the energy and nature of the particle is obtained by comparing the pulse height per unit energy of a 5.3-Mev alpha particle with that of a high-energy electron. This measurement is commonly referred to as the alpha-to-beta ratio. It varies from about 9% for most organic scintillators to nearly 100% for a few inorganic scintillators.

The energy dependence of scintillation efficiency is more precisely described by expressing the incremental scintillation efficiency, dN/dE, or the specific scintillation efficiency, dN/dx, as a function of E, where dx is the incremental distance traversed by the particle. In particular, Taylor *et al.* have shown that these incremental efficiencies may be expressed as a unique

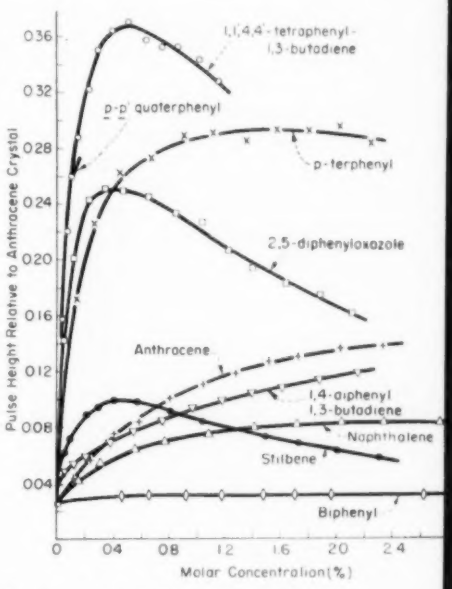

FIG. 3. Pulse height vs concentration in solid solutions with beta-particle excitation

function of the specific energy loss, dE/dx. Experimental evidence of this is seen in Fig. 4, where the data of Taylor *et al.* for various particles on anthracene are plotted to show dN/dx as a function of dE/dx. The only strong deviation from a smooth curve is seen in the case of low-energy electrons. Birks (*12*) has shown that such a deviation occurs wherever the range of the particle in the scintillator is less than about 7 microns. Birks attributes this to a surface effect in which the energy that can migrate to the surface is assumed to be quenched. According to this picture, such discrepancies would not occur if an internal source of radiation were used.

Birks (*13*) has also derived a the-

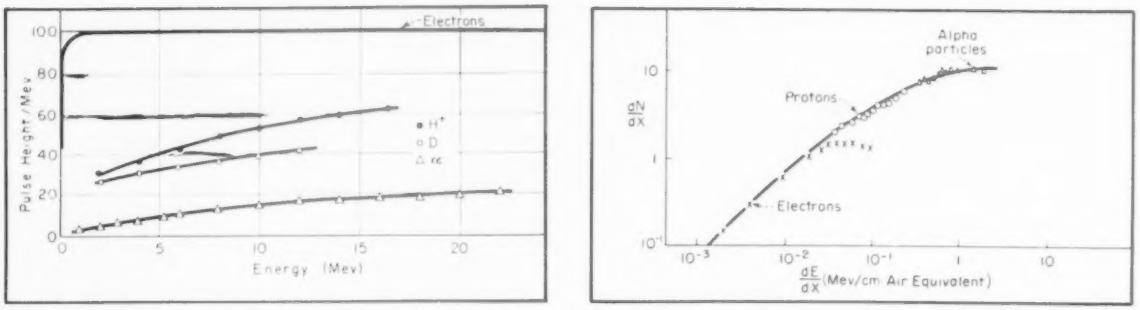

FIG. 4. (Left) Dependence of scintillation amplitude of anthracene on particle energy and (right) incremental scintillation efficiency vs specific energy loss

oretical formula to account for the decrease of scintillation efficiency with increasing specific energy loss. This theory is based on the assumption of quenching by impurities produced in the wake of the particle as a result of chemical dissociation. The effect of this quenching is essentially a local reduction in the fluorescence quantum efficiency, and accordingly a reduction in the incremental scintillation efficiency, i.e.,

$$\frac{dN}{dE} = \frac{q}{w}\left(\frac{1}{1+kc}\right) \qquad (7)$$

where c is the concentration of the quenching impurity and k is the quenching constant. Since the quenchers are assumed to be produced as a result of dissipation of the particle's energy, it is expected that their concentration will be proportional to the specific energy loss

$$c = B\,dE/dx$$

$$\frac{dN}{dE} = \frac{q}{w}\left(\frac{1}{1+kB\,dE/dx}\right) \qquad (8)$$

The scintillation amplitude N is then obtained from Eq. 8 by integration over the range of the particle.

Birks has shown that the calculations based on this theory give excellent agreement with experimental curves of pulse height as a function of energy for electrons, protons, deuterons and alpha particles on organic crystals. The importance of this theory is seen in the fact that the quantity kB can be determined from a measurement of the alpha-to-beta ratio. One can then calculate the response of the scintillator for any other particle or energy, using available range-energy relationships.

One weakness in Birks' theory is the fact that it predicts a decay time that varies with specific energy loss in the same manner as the scintillation efficiency, a prediction that appears to disagree with observation. This objection is overcome in a theory proposed by Wright. The derivation of Wright's formula (*14*) is similar to Birks' with one exception: whereas Birks pictures the quenching as being due to permanently formed quenching agents, Wright's model describes the loss of excitation energy in terms of quenching interactions between neighboring excited molecules. This model gives rise to a bimolecular decay law, and predicts that the variation of scintillation efficiency with specific energy loss is described by an equation of the form

$$\frac{dN}{dE} = \frac{q}{w}\,\frac{\ln(1+M\,dE/dx)}{M\,dE/dx} \qquad (9)$$

where M is a constant related to the alpha-to-beta ratio.

Although the form of Wright's equation is different from Birks', their shape is sufficiently similar that the present accuracy of experimental data of scintillation efficiency vs particle energy is inadequate to decide between them. One feature of Wright's theory that should be amenable to experimental verification is the fact that the decay of luminescence following excitation by an alpha particle should consist of a large fast spike at very short times that reverts to an exponential decay at larger times. Observation of this spike would require a system with a band pass of the order of 1,000 Mc.

Important Scintillators

It may be helpful to review the salient luminescent properties of the more important scintillators.

Scintillation efficiency. Many reports have been made of the relative efficiency of various scintillators. A few values have been tabulated in Table 1 for the more common scintillators, together with wavelengths of maximum emission. In general, the efficiency is expressed in terms of the relative response of the type 5819 photomultiplier. This type of comparison leaves much to be desired. However, except for LiI(Sn), the scintillators listed all emit in the region of the broad maximum in the response of this photomultiplier.

To convert relative efficiency values into absolute values, it is necessary to have an absolute measurement for one of the scintillators. Several investigators have undertaken to measure the efficiency of anthracene. Table 2 gives their results.

Decay time. Another important scintillator property is the decay time. This property is particularly important for organic scintillators, which are frequently used for high-speed work. The decay time is also a very fundamental property of the scintillator, and its measurement can often settle a crucial question regarding the physical processes involved in the scintillator. A rough measurement of the decay time of a particular scintillator specimen is easily made. But an accurate measurement of the true molecular lifetime

TABLE 2—Absolute Efficiency of Anthracene for Beta Particle Excitation

Investigator	*Date*	*Efficiency* (%) (Nhv·E ×100%)	*Energy to make a photon* (ev)
Harrison	1951	4.2	65
Birks	1953	3.7	70.5
Kallmann	1953	10	26.5

is extremely difficult, and in certain cases almost impossible to make.

One major obstacle to accurate decay-time measurements is the purity of the specimen. Since it is known that small amounts of impurities can trap and quench the excitation energy of a scintillator, it is probable that the resulting competition with the emission process reduces the decay time below its value for the pure material.

A second major difficulty is the effect of self-absorption. This effect, described by Birks (*15*), can be illustrated with the aid of Fig. 5. Assume that of the N photons emitted in a scintillation, $k_e N$ escape the scintillator on the first try and $(1 - k_e)N$ are reabsorbed. If we can assume that this reabsorption occurs near enough to the point of origin that the probability of escape on the second try is essentially the same as the first try, then the status of the reabsorbed photons is the same as though no emission had occurred. In other words, the emission probability p_e must be replaced by the smaller quantity $k_e p_e$. Thus, the decay is still exponential, but the decay time is longer, and the quantum efficiency is lowered. The new quantum efficiency and decay time are

$$q = q_0 \left[\frac{k_e}{1 - q_0(1 - k_e)} \right] \quad (10)$$

$$\tau = \tau_0 \left[\frac{1}{1 - q_0(1 - k_e)} \right] \quad (11)$$

where q_0 and τ_0 are the molecular quantum efficiency and decay time, respectively. It can be shown that if the thick-specimen emission spectrum is normalized to coincide with the thin-specimen emission spectrum at long wavelengths, as shown in Fig. 6, then the ratio of areas b/a is identical with k_e. Birks has measured this ratio for anthracene using microcrystals and a 1-cm-thick specimen, finding $k_e = 0.2$ for the thick specimen. With the value of 0.9 for q_0, this gives $\tau = 3.6\,\tau_0$.

Thus, according to these results, decay-time measurements made on thick samples may be many times larger than the values obtained for microcrystals. Also, the decay time of a thick sample is affected by the presence of a reflector and by the degree of penetration of the exciting radiation. Thus, this factor alone is large enough to account for many of the large discrepancies found in the literature.

Effect of photomultiplier. Another factor that limits the accuracy of measurement of decay times is the contribution of the photomultiplier. The transit-time spread of photomultipliers ranges from the order of 1 mμsec upwards, depending on the number of stages, degree of focussing, and the applied voltage. If a spread in transit time had a Gaussian form, it would be expected that scintillators whose decay time was two or more times the standard deviation of the Gaussian could be measured with fair accuracy. However, recent observations indicate that the response of a photomultiplier may deviate considerably from the Gaussian form, having instead a fast rise followed by a decay that is rapid at first, but becomes slower at longer times.

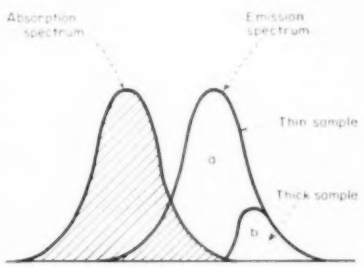

FIG. 5. Effect of thick-sample self-absorption on emission

This effect is illustrated in Fig. 6, which shows an amplified noise pulse from a type C-7165A photomultiplier. The high gain and output current of this photomultiplier made this observation possible without the use of external amplifiers. A photomultiplier response of this type, although it is of little importance in scintillation counting, introduces errors in the measurement of the decay time of a very fast scintillator that are not easily accounted for.

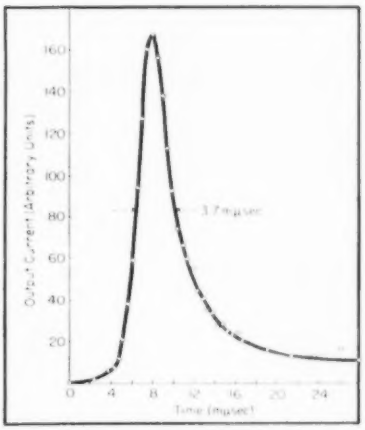

FIG. 6. Anode pulse from C-7165A photomultiplier resulting from amplification of single cathode electron

A smaller time dispersion is found in the type C-7164A photomultiplier, but the form of the response is unknown. A number of scintillators have been measured with this photomultiplier at Argonne National Laboratory, using pulsed X-ray excitation. A summary of values for some common organic scintillators is given in Table 3. With a plastic scintillator containing terphenyl (decay time ≤ 2.8 mμsec) as a source of ultraviolet radiation, it was possible to measure the decay time of an anthracene crystal under ultraviolet excitation. The value of the decay time for ultraviolet excitation was smaller than the X-ray value by 7%.

TABLE 3—Scintillation Decay Times for 8-kv X-Ray Excitation

Scintillator	*Decay time* (mμsec)
Anthracene	32–35
Stilbene	6–4
Diphenylacetylene	5.4
Toluene + 5 gm/liter *p*-terphenyl	≤2.8
Polyvinyltoluene + 4% *p*-terphenyl + 0.1% diphenylstilbene	≤2.8
Polystyrene + 1.8% tetraphenylbutadiene	5.0

BIBLIOGRAPHY

1. M. S. Livingston, H. A. Bethe, *Revs. Mod. Phys.* **9**, 263 (1937)
2. R. C. Sangster, "A Study of Organic Scintillators," M.I.T. Technical Report No. 55 (Jan. 1, 1952)
3. H. Kallmann, M. Furst, *Phys. Rev.* **78**, 621 (1950); *Phys. Rev.* **79**, 857 (1950); *Phys. Rev.* **81**, 853 (1951)
4. M. G. Schorr, F. L. Torney, *Phys. Rev.* **80**, 474 (1950)
5. W. S. Koski, *Phys. Rev.* **82**, 230 (1951)
6. L. Pichat, Y. Koechlin, *J. chim. phys.* **48**, 225 (1951)
7. R. K. Swank, W. L. Buck, *Phys. Rev.* **91**, 927 (1953); W. L. Buck, R. K. Swank, NUCLEONICS **11**, No. 11, 48 (1953)
8. F. B. Harrison, Ph.D. thesis, Princeton University (1951)
9. T. Förster, *Ann. Physik* **2**, 55 (1948)
10. J. Franck, R. Livingston, *Revs. Mod. Phys.* **21**, 505 (1949)
11. C. J. Taylor, W. K. Jentschke, M. E. Remley, F. S. Eby, P. G. Kruger, *Phys. Rev.* **84**, 1034 (1951)
12. J. B. Birks, *Phys. Rev.* **86**, 569 (1952)
13. J. B. Birks, *Phys. Rev.* **84**, 364 (1951)
14. G. T. Wright, *Phys. Rev.* **91**, 1282 (1953)
15. J. B. Birks, W. A. Little, *Proc. Phys. Soc.*, **A66**, 921 (1953)

Flying-spot scanner can show . . .

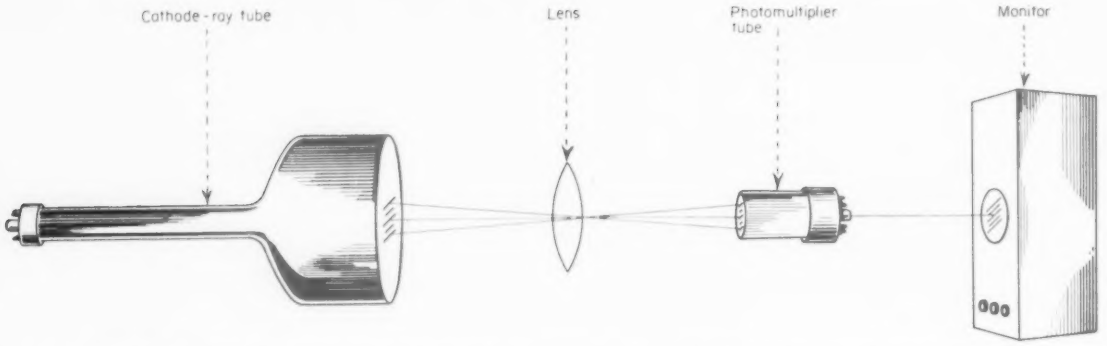

FIG. 1. Flying-spot scanner uses lens to focus spot of light on photocathode. Multiplier anode current displayed on monitor

New Photomultipliers

While developing larger and larger photomultipliers, with a 16-in. tube now being constructed, Du Mont is also using a flying-spot scanner to study tubes that are in production. Data on 5, ¾, and 1¼-in. tubes are given in this article, and the use of wide dynodes to improve gain is discussed

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THE PURPOSE of this article is to present more operational data on the Du Mont photomultipliers introduced in an earlier paper* by the author and to present recent developments that have taken place recently at these laboratories.

The tubes to be discussed all utilize the box-type dynode structure with activated silver-magnesium secondary emission surfaces. They differ mainly in photocathode sizes and numbers of dynodes. The table on this page lists the tubes to be discussed, along with their main physical characteristics.

Besides taking a number of pulse-height analyses on these tubes, a means of testing with a flying-spot scanner apparatus has been used. The principle of this apparatus is illustrated in Fig. 1. A sharply focused electron beam is swept across the face of a cathode-ray tube. The resultant spot of light is then focused onto the cathode of the photomultiplier to be tested. The signal from the anode of the multiplier is then fed to a monitor. This monitor may be either a standard oscillograph or a television monitor.

By sweeping the light spot on a line across the photocathode one can obtain on an oscillograph a plot of anode output as a function of the light-spot position on the line across the photocathode. Figures 2 and 10 were obtained this way. By sweeping the spot across the whole photocathode, one can display the anode output on a standard television screen and obtain what amounts essentially to a picture of the photocathode as seen by the anode of the photomultiplier. Figures 3, 4, 11 and 12 were obtained in this manner.

The 5-in. K1198

The K1198 is a photomultiplier with a 5-in. diameter front end.* The actual cathode diameter is 4½ in. The main use of these tubes is with large area scintillators such as have recently come into being for total-absorption spectrometers. The use of a large area crystal in gamma-ray spectroscopy will decrease the Compton scattering continuum relative to the photoelectric peak and allow more accurate analysis of complex gamma-ray spectra. It has also found use in coincidence counting, since in a total-absorption spectrometer coincident gamma rays will not appear as separate peaks but rather as one peak corresponding to the sum of the energies.† These tubes are also useful

* Five new photomultipliers for scintillation counting, NUCLEONICS **11**, No. 9, 30 (1953).

† P. R. Bell, (see p. 54).

response across cathode . . .

FIG. 2. Oscillograms from scanner for K1198 photomultiplier. Shield plate was at optimum (top) and at dynode-1 potential (below)

or give complete picture of cathode uniformity

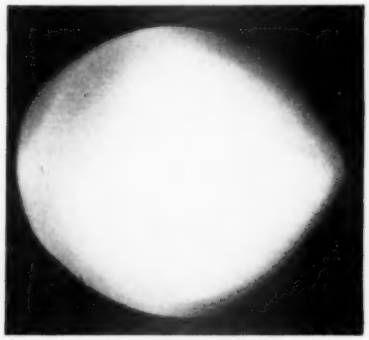

FIG. 3. Full scanning of photocathode of K1198 tube produced this pattern on monitor. Poor photoelectron collection is indicated; shield was at dynode-1 potential

FIG. 4. Same full scanning as in Fig. 3 of photocathode of K1198 tube shows uniformity of anode output for shield at cathode potential

and Operating Data

where banks of photomultipliers are required since they have a cathode area approximately nine times greater than a 2-in. tube.

A standard box-type dynode structure is used with a shield plate whose potential may be independently varied (*1*). The importance of this variable shield for optimum photoelectron collection can be illustrated by some photographs taken on a flying-spot scanner. The top oscillogram in Fig. 2 shows the anode output for the shield at cathode potential. Note that the collection from the edge is relatively good. The lower oscillogram was taken under the exact same conditions but with the shield at dynode-1 potential. Here the slumping at the edges is quite noticeable—indicating poor photoelectron collection for this shield potential.

These Are the Photomultipliers for which Data is Given in this Article

Tube type	*Front-end diameter (in.)*	*Number of stages*
K1198	5	10
K1231	$1\frac{1}{4}$	10
K1193	$\frac{3}{4}$	10
K1209	5	12
K1213	3	12

This situation is shown more graphically in Fig. 3. Here the spot of light moves over the whole cathode, and the anode output is displayed on a television screen. The dark spots at the edges indicate poor photoelectron collection for the shield at dynode-1 potential. Figure 4 shows the uniformity of anode output for the shield at cathode potential. Here the collection from the edge is very good.

To bring these results into the field of scintillation counting, a number of pulse-height analyses were run using NaI crystals and a Cs^{137} source. The data are displayed in Fig. 5. Here the pulse height is plotted as a function of shield potential for three different crystal positions—center, edge, and halfway between center and edge. The shield potential starts at dynode-1 potential and is varied down to cathode potential.

For the crystal positioned at the center the pulse height is a maximum with the shield at dynode-1 potential; with the crystal on the edge the maximum occurs with shield at cathode potential; while halfway between center and edge the maximum occurs for a shield potential between cathode and dynode-1. Thus for a large scintillator the optimum shield potential will be somewhere between cathode and dynode-1.

The energy resolution tends to improve with increasing pulse height, as would be expected from improved photoelectron collection. This is shown in Fig. 6. Note that while the resolution improves for the edge it degenerates for the center. Thus for both optimum pulse height and resolution using a crystal that covers the whole cathode, some in-between potential is necessary.

Another interesting question is how the pulse height and resolution vary with increasing voltage between the cathode and dynode-1. This variation is illustrated in Fig. 7. The data here were taken with a $\frac{3}{4}$-in. crystal at the edge of the tube. It will be noted that while the resolution improves initially, it levels off above a certain voltage; the pulse height increases monotonically. This is consistent with data shown for the 2-in. tube (*1*) although the voltage has been taken somewhat higher here. The initial improvement is probably due mainly to improved statistics on the first stage due to increasing multiplication. After a point, however, this increasing multiplication does not improve the over-all tube statistics any and the resolution levels off.

The $\frac{3}{4}$-in. K1193

For small space requirements a $\frac{3}{4}$-in. diameter ten-stage photomultiplier has been developed. Figure 8 shows this tube and its multiplier structure. The first dynode is somewhat off center,

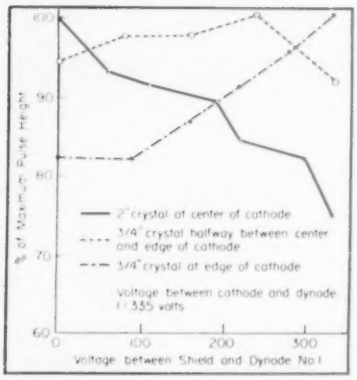
% of Maximum Pulse Height
2" crystal at center of cathode
3/4" crystal halfway between center and edge of cathode
3/4" crystal at edge of cathode
Voltage between cathode and dynode 1 = 335 volts
Voltage between Shield and Dynode No.1

FIG. 5. Variation of pulse height with shield voltage for K1198

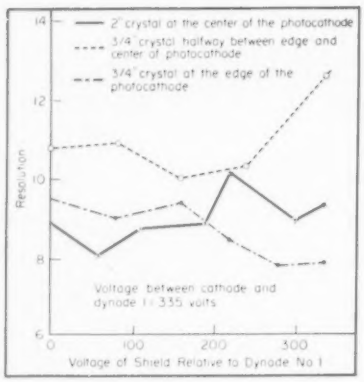
2" crystal at the center of the photocathode
3/4" crystal halfway between edge and center of photocathode
3/4" crystal at the edge of the photocathode
Resolution
Voltage between cathode and dynode 1 = 335 volts
Voltage of Shield Relative to Dynode No.1

FIG. 6. Variation of resolution with shield voltage for K1198

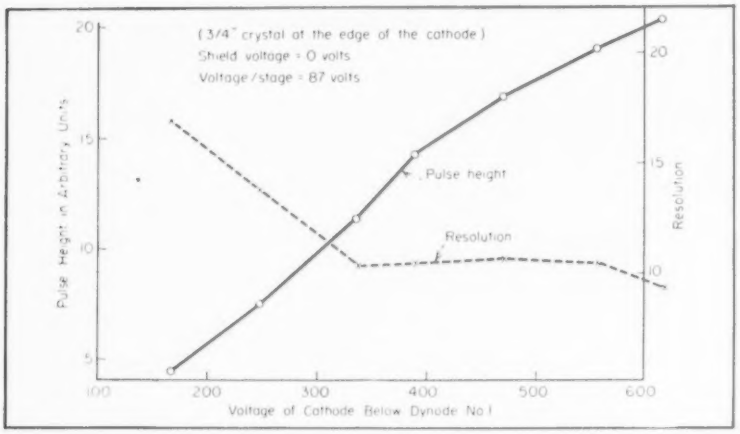
(3/4" crystal at the edge of the cathode)
Shield voltage = 0 volts
Voltage/stage = 87 volts
Pulse height
Resolution
Pulse Height in Arbitrary Units
Resolution
Voltage of Cathode Below Dynode No.1

FIG. 7. Variation of pulse height and resolution with voltage between cathode and dynode-1 for K1198

but this is necessary to fit this box dynode type of structure into the $^3/_4$-in. glass tube. As a result the shield potential must be adjusted for optimum photoelectron collection.

Figure 9 shows the variation of anode output with shield voltage. The shield voltage is varied from cathode to dynode-1. The one curve was taken with a steady luminous light incident on the photocathode; the other was taken with a Cs^{137} source and a NaI crystal. Both curves show a big drop in output for the shield at dynode-1 potential. The maximum lies somewhere between cathode and dynode-1. This very large drop is probably a direct result of the off-centering of the first dynode.

Again, the flying-spot scanner illustrates these results very well. Figure 10 shows an oscillogram that, like Fig. 2, is essentially a plot of anode output for excitation along a line on the cathode. Here the output with shield at dynode-1 potential is clearly worse than the optimum shield potential. Note that for the optimum condition the collection from over the whole cathode is quite uniform. Figure 11 illustrates this uniformity while Fig. 12 shows how the photoelectron collection degenerates with the shield potential at dynode-1 potential.

The particular tube used for taking this data had a gain of about 80,000 at 105 volts/stage. With a $^3/_4$-in. NaI crystal and a Cs^{137} source, a resolution of 12.2% was obtained.

These are the results of the first developmental models. Present plans will have this tube in production in one or two months, but as yet no production quantities have been produced.

The $1^1/_4$-in. K1231

At present the next smallest size to the $^3/_4$-in. diameter photomultiplier is the $1^1/_4$-in. size—type K1231. This differs from the $1^1/_2$-in. tube (6291) in several details.

In mechanical dimensions the glass bulb is somewhat smaller than the $1^1/_2$-in. diameter 12-pin base which is used. This allows use of a mu-metal shield for magnetic shielding without exceeding the outside base diameter. Also, the fact that the glass bulb fits more loosely into its base allows tighter tolerances to be held on over-all length of the tube.

Another point of difference is that in the $1^1/_4$-in. tube the shield is connected internally to the cathode instead of the first dynode. In Fig. 13 anode output is plotted against shield voltage. Output and hence photoelectron collection reaches its maximum with the shield at or near cathode potential. For this reason in production models the shield has been connected internally to cathode potential. The reason the shield cannot be brought out on a separate pin in the base is that all 12 pins are taken up by the 10 dynodes, cathode, and anode.

Wide Dynodes

While in a good many applications pulse height is not important, some applications require a large pulse height. To get this using silver magnesium dynodes, it has been necessary to run the voltage as high as 125 to 150 volts/stage. In experiments with the box-type dynode structure used on Du Mont photomultipliers, it was found that the simple expedient of making the dynode itself wider gave a noticeable increase in gain—by as much as a factor of two to three.

This change has been made in several developmental tubes and will be incorporated in the 2-in. tube (type 6292) in the near future. The difference in dynode width is shown in Fig. 14.

While the average multiplication of a 10-stage tube with the narrow dynodes is 200,000 at 105 volts/stage, the gain with wide dynodes is from 400,000 to 600,000. One recent development with these dynodes has been the construction of a 12-stage high-gain multiplier structure. This structure has been incorporated into the 3-in. (K1213) and 5-in. (K1209) photomultipliers. These tubes are particularly useful where one wants high gain at low voltage per stage to keep ohmic leakage at a minimum. At 90 volts per stage these structures give a gain

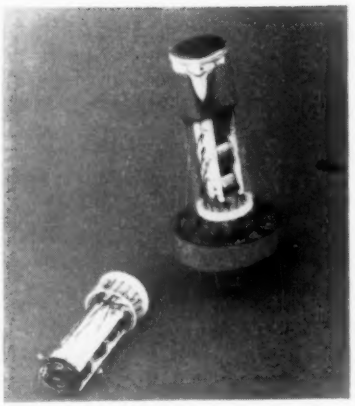

FIG. 8. Type K1193 is a $\frac{3}{4}$-in. diameter photomultiplier

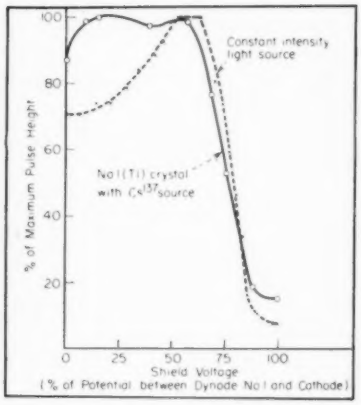

FIG. 9. Variation of anode output with shield voltage for K1193

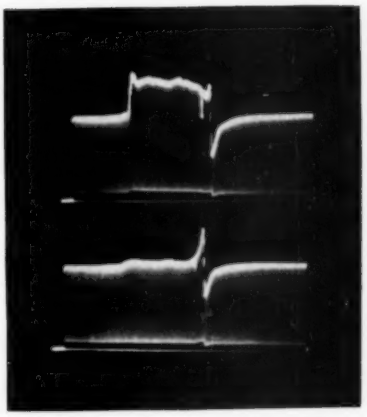

FIG. 10. Oscillograms for K1193. Shield at optimum (top) and dynode-1 potential

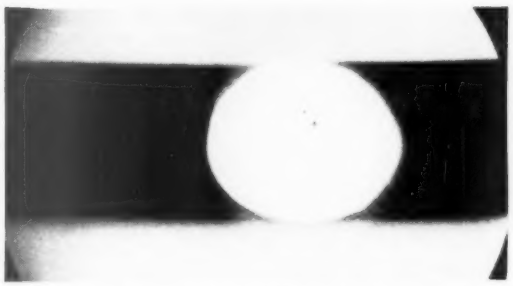

FIG. 11. Full scanning of K1193 photocathode produces this display of anode output on flying-spot scanner monitor when shield is at optimum potential

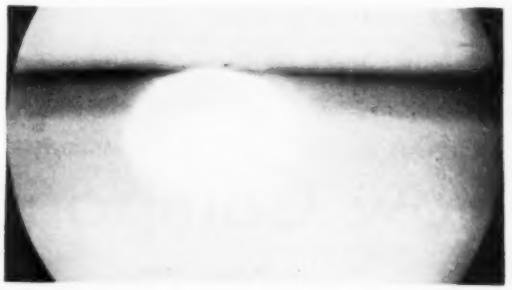

FIG. 12. Same full scanning as in Fig. 11 of K1193 photocathode shows degeneration of photoelectron collection with shield at dynode-1 potential

of 3 to 7 $\times$ 10^6. At 105 volts per stage the gain is as high as 7 $\times$ 10^2. These tubes have not as yet been designed to minimize space-charge saturation so that they probably cannot be used to observe pulses directly on a cathode-ray tube. However, the condition of higher gain at lower voltage is always a desirable one.

Future Developments

At present, the largest size photomultiplier developed at these laboratories is a 7-in. diameter tube. Only one of these has been built, and no quantitative data are available at present. Construction of a 16-in. diameter photomultiplier is well underway and should be completed in the near future. The ultimate goal is a 30-in. diameter photomultiplier, but this is quite a bit in the future.

* * *

The photomultipliers developed by these laboratories are the result of the combined efforts of many people. Particular acknowledgement in this regard is due to Philip Snell, the project engineer on this work, and Arthur Williams, who constructed the multiplier sections during the developmental work. The flying-spot scanner equipment was designed by R. C. Palmer, to whom the author is indebted for many suggestions on the applicability of this equipment to photomultiplier testing. Many of the measurements referred to were performed on equipment belonging to the Instruments Branch of the Health and Safety Division, N.Y.O.O., A.E.C. The author is also indebted to H. D. LeVine and R. T. Graveson for many stimulating discussions during the development of these photomultipliers. Finally, the author wishes to express appreciation to S. J. Koch and R. E. Rutherford, Sr., who directed the work, for their continued encouragement and valuable suggestions.

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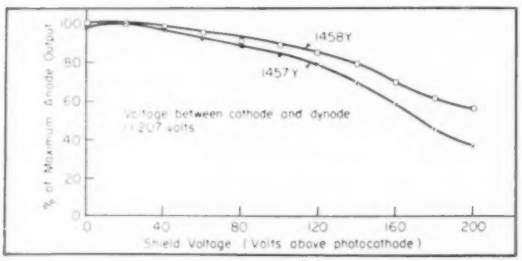

FIG. 13. Variation of anode output as a function of shield voltage for K 1231 photomultiplier

FIG. 14. Comparison of standard box-type dynode (left) with new wider dynode

While liquid scintillators emit no measurable fraction of their light with decay times of 0.1 to several hundred μsec, plastics and crystals do. Organic solids all appear to have two components, one about 3 μsec, the other longer

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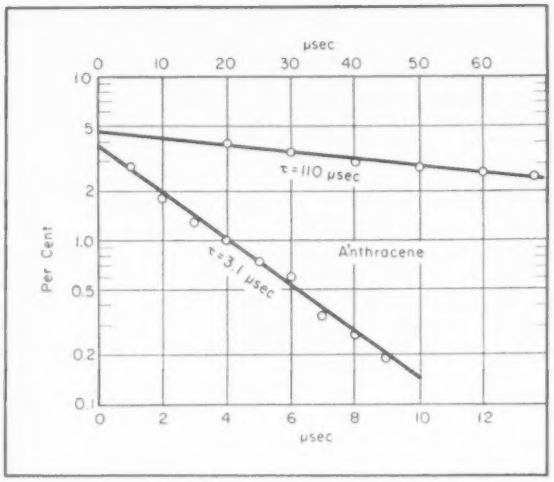


FIG. 1. Decay of slow components in anthracene. Upper curve goes with upper scale. The 110-μsec component was subtracted from measured values to get points for 3.1-μsec curve

Slow Component in Decay of Fluors

MEASUREMENTS have been made of decay times in scintillation crystals, plastics and solutions in the range of a few tenths of a microsecond to a few hundred microseconds (*1–3*). The scintillator was wrapped in aluminum foil, or in the case of the liquids, placed in a beaker lined with aluminum, because this material did not phosphoresce. It was bombarded with X-rays of around 70 kv, and viewed with a type C-7164 photomultiplier selected for its freedom from afterpulsing. The signals were presented on a Tektronix type 517 oscilloscope, photographed, and measured with a comparator.

Both the X-ray tube and the photomultiplier were gated, the X-ray tube by means of a grid, and the photomultiplier by making the first dynode and shield 8 volts negative with respect to the cathode. Normally, the X-ray tube was on, the photomultiplier off.

The sequence of events was the following: The photomultiplier was gated on, the X-ray tube was gated off, the photomultiplier was gated off. The X-ray tube came back on after 100 μsec, so that at repetition rates of a few a second, it was essentially on steadily.

Since the scintillator is irradiated for a time long compared to the decay times to be measured, an equilibrium is established between the different modes of light emission. Then, when the X-ray beam is cut off, each mode falls with its characteristic decay time. By plotting the decay curves, and extrapolating each component to zero time, we can find the actual fraction of light emitted in any one mode.

In this respect the method is different from one employing a short burst of irradiation, where an extrapolation of the tail would give a height proportional to the fraction of light in any component divided by its decay time. The method used in this experiment therefore enhances the components with long decay times, which are the ones we are trying to measure.

There are several mechanisms that could explain an apparent slow component, among them afterpulsing in the photomultiplier and a failure of the X-ray tube to cut off completely. Fortunately, measurements with liquid scintillators have shown not more than about 0.1% residue after 1 μsec (*2*), and this gives an upper limit to all these effects, as well as the slow component from the liquids. For most of the measurements presented here, a photomultiplier was used that showed 0.3–0.4% residue after 1 μsec for the liquids; this was ascribed to afterpulsing, and this amount was subtracted from all the other curves.

Results

The liquids on which measurements were performed were various combinations of terphenyl, diphenyl oxazole, diphenyl oxadiazole, αnaphthyl phenyl oxazole (αNPO) and diphenyl hexatriene in toluene, xylene, benzene and phenylcyclohexane. There was no evidence in any of them of a slow component 1 μsec after the X-ray cut-off, within the accuracy of the measurement, which was about 0.2%.

Figure 1 shows the results of measurements on anthracene. The compo-

nent with the long decay time has been subtracted from the data at short times, giving the points shown on the lower curve. It appears that there are two components with decay times of 110 and 3 μsec, respectively. When these are extrapolated back to zero time, the time of X-ray cut-off, they indicate that about 4½% of the light comes out with the longer, and 3½% with the shorter decay time.

The results are summarized in the table on this page. All of the organic solids appear to have one component with a decay time of about 3 μsec, and one longer one. Two plastics were measured, polystyrene-terphenyl-αNPO and polyvinyltoluene-terphenyl-diphenylstilbene, and gave the same results. Judging by the reproducibility of the measurements, the figures in this part of the table are probably accurate to 10–15% except for the 40 μsec for plastics, which is very rough.

For NaI, Emigh and Megill (*4*) have found several components with decay times from 13 sec up to several hours, with light outputs totaling about 3%. Our measurements show one component with an apparent decay time of 200 μsec (which might well be the sum of components with longer and shorter mean lives), and something with a mean life in the neighborhood of 1–13 sec, with about 1.5% remaining after 1 sec. There appeared to be nothing between the 0.25-μsec decay time of the fluorescence and the component listed as 200 μsec.

To look for components with shorter lifetimes, some photographs were taken with a faster sweep. Figure 2 shows the results of measurements on terphenyl-toluene. For want of better information, since the liquids appear to have no slow component, and since the decay time of their fluorescence is much shorter than the times measured here, we have taken this to represent the cut-off time of the X-ray beam. It is evident from this curve that measurements of decay times in the region of tenths of a microsecond will not be very accurate.

Figure 3 shows a similar measurement on a terphenyl crystal.

Similar measurements were made with stilbene, anthracene, and a plastic scintillator. For each of these, there was evidence of a component in the range of tenths of a microsecond. In the case of stilbene and the plastic, it was possible to get good agreement with the terphenyl-toluene curve by subtracting one exponential component. In the case of anthracene, it was necessary to correct the X-ray cut-off curve for the 30-mμsec decay time of the anthracene fluorescence before the curves could be made to agree. The decay times of the fluorescence of terphenyl, stilbene and the plastic are too short to affect the shape of the X-ray cut-off curve materially.

The last column of the table shows a tabulation of results. Because of all the subtractions necessary, these are quite rough, particularly in the case of anthracene, where the extra correction was necessary. These decay times could better be measured with an X-ray tube that can be cut off sharply. If such a tube were pulsed on for perhaps a microsecond so as not to build up the slower components to equilibrium, there would be less to subtract.

Discussion

The results shown in the table should be taken to supersede ones published earlier (*2*). In the earlier results the different components were not resolved, and no correction was made for non-linearity of the amplifier. The lack of agreement between the present results and those of Meyer and Maier indicates the desirability of repeating the experiment with apparatus better capable of short time measurements.

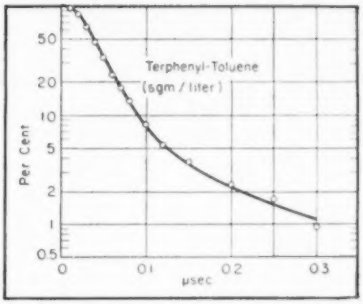


FIG. 2. Measured decay time of signal from terphenyl-toluene solution

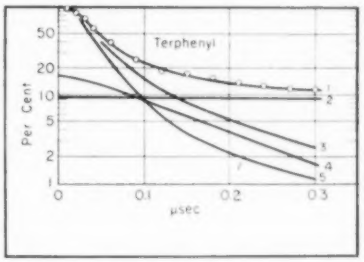


FIG. 3. Decay of signal from terphenyl crystal: Curve 1, measured points; 2, decay times from table; 3, result of subtracting 2 from 1 and renormalizing to 100%; 4, approximately 15% with τ = 120 mμsec; 5, result of subtracting 4 from 3 and renormalizing. This agrees well with Fig. 2

The existence of slow components in the solids makes liquid scintillators seem most desirable for use with fast timing circuits. This follows from the relatively long decay time of the fluorescence in anthracene, and the fact that liquid scintillators are now available whose light output is quite comparable to that part of the fluorescence of stilbene that decays with a mean life of 6 mμsec (*5*).

Slow components will affect the comparison between the measurements of the light output of a scintillator by the pulse-height and current methods, and will make the results of a pulse-height measurement dependent on the time constant of the integrating circuit.

* * *

This work was done under the auspices of the U. S. Atomic Energy Commission.

Decay Times of Slow Components, with Fraction of Total Light Emitted in Each

	%	*Period* (μsec)	%	*Period* (μsec)	%	*Period* (μsec)
Solutions: No slow component						
Anthracene	4.5	110	3.5	3	15	0.120
Stilbene	5	80	5.5	4	6	0.250
Terphenyl	3.5	80	5.5	3	15	0.120
Plastic	0.7	~40	4	2.5	6	0.130
NaI	8	~200				
	1.5	1 sec $\lesssim \tau \lesssim$ 13 sec				

BIBLIOGRAPHY

1. L. Bittman, M. Furst, H. Kallmann, *Phys. Rev.* **87**, 83 (1952)
2. J. A. Jackson, F. B. Harrison, *Phys. Rev.* **89**, 322 (1953)
3. K. P. Meyer, A. Maier, *Helv. Phys. Acta* **26**, 411 (1953)
4. C. Emigh, L. Megill, private communication
5. F. N. Hayes, private communication

Phosphors and Photomultipliers

Some recent developments in multiplier phototubes, by Ralph W. Engstrom, Radio Corporation of America, Lancaster, Pa. The acceptable quality level for photocathode sensitivity on the 5819 multiplier phototube has been increased from 20 μa/lumen in 1952 to 40 μa/lumen in 1953. In addition, the blue sensitivity on production sampling, shown in Fig. 1, ran from 1 to 5 μa/blue lumen in 1952; in 1953 the spread of tubes ran from 4 to 8 μa/blue lumen. The support of the accelerating electrode has been changed to a quenched ceramic since there had been cases reported where the unquenched material may glow due to bombardment; this could cause feedback to the photosensitive surface.

The 6342 multiplier phototube is the same size as the 5819 and has the same cathode sensitivity. The internal configuration of this tube and the 5819 is shown in Fig. 2. The grill in the accelerator plate on the 5819 was a double wound grid and transmitted 75% of the incident electrons. The 6342 uses a single wound grid with larger spacing, and now will transmit 92% of these electrons. It has a flat face, and the accelerating electrode has been brought out on a separate lead such that it can be used for focusing. Flying-spot-scanner data shows that the focusing electrode potential can be varied to improve the uniformity of response across the cathode surface. This tube has silver-magnesium dynodes and is processed to higher temperatures; this has the effect of reducing afterpulsing.

The 6372 has a large semicylindrical cathode transmission plate practically $4\frac{1}{4} \times 3\frac{1}{8}$ in. in size. The uniformity of the cathode along the axis is within 12% approximately, and collection efficiency radial is uniform from −30 to +30 degrees and drops slowly outside these limits to the total cathode angle of 150 degrees.

The 16-stage multiplier phototube, C7165A, has a gain up to 10^9 and an output in the region of 100 to 200 ma on a twin-lead output of 150 ohms impedance. The photocathode is approximately $\frac{3}{8} \times \frac{1}{2}$ in. This tube is useful for high speed pulse work where such high gains and current outputs are necessary.

RCA has in development at the present time several experimental tubes. The H5723 is a $\frac{3}{4}$-in. diameter tube. The H5037 is a 4-in. diameter head-on cathode containing an electron optical focusing system that has a collection efficiency of better than 90%. The H5914 is similar to the C7165A mentioned above. However, it has a 2-in. diameter photocathode.

It was reported from the floor that the 6342 has a transit time from one dynode to the next of approximately 2 mμsec and that the half width of a single electron pulse is approximately 3 μsec. Also, the transit time spread from the edges of the photocathode as compared to the center of the photocathode to dynode is different by 30 to 40%. This accounts for one of the main causes of transit time spread in multiplier tubes.

When using organic as compared to inorganic phosphors, it was pointed out that the space-charge limitation will occur at a lower voltage pulse since the total charge obtained from the anode will occur in a shorter time because organic materials emit their light with a much shorter decay time.

Production of plastic phosphors in quantity, by L. Wouters, University of California Radiation Laboratory, Berkeley, Cal. Because polymerization of plastic scintillators is exothermic, orthodox production methods require careful control of temperature. But a procedure has been developed in which the monomer is heated to the reaction temperature and the polymerization allowed to proceed exothermally.

Processing is carried on in a reaction vessel 6 in. in diameter and 20 in. high. This is surrounded by a mineral-oil bath heated to 150° C by 90-psi steam. On top of the reaction vessel is a reflux column.

At the start of the process, the vessel is only half filled with the monomer, activator, and wavelength shifter. When the reaction temperature is reached, violent boiling occurs, lasting for about $\frac{1}{2}$ hr. In about 3 hr, the mixture is viscuous; $\frac{1}{4}$ of the monomer is then added and

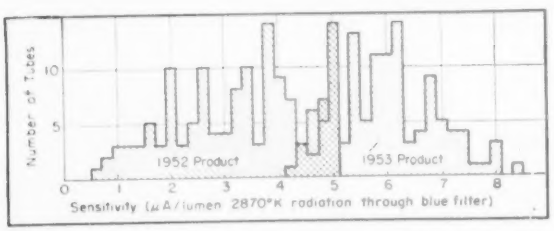


FIG. 1. Comparison of production samples for two years on RCA 5819 multiplier (Engstrom)

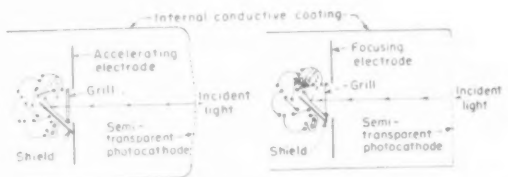


FIG. 2. Configuration of old 5819 (left) and 6342 multiplier tubes. New 5819 has single-wound grill (Engstrom)

the boiling repeated. The last ¼ of monomer is then added.

About 6 hr later, polymerization is completed. The product is allowed to cool overnight; the reaction flask is broken and the bottom placed in a box of housing insulation to cool for 4 days.

The present scintillator, chosen after tests with test tubes heated in a beaker of mineral oil on a hot plate, is: styrene solvent, 2½% terphenyl activator, 0.03% terphenyl butadiene wavelength shifter, and 0.01% zinc stearate to make removal of the plastic from the glass vessel easier. Cadmium stearate was tried, but it did not produce a satisfactory neutron-sensitive phosphor.

Vinyl toluene showed 30–40% greater efficiency of conversion in small samples, but this does not appear to be so in large samples.

Delay time of the styrene plastic phosphors is 5 mμsec.

This process is based on a method developed by Earl Fullman at Los Alamos Scientific Laboratory.

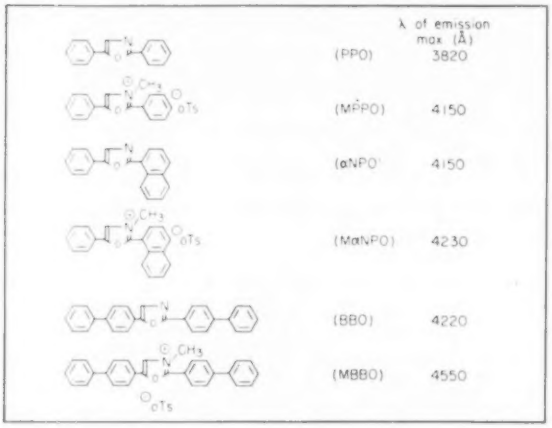


FIG. 3. Structure and maximum-emission wavelength for newer wavelength shifters (Hayes)

New liquid scintillators, by F. N. Hayes, University of California, Los Alamos Scientific Laboratory, Los Alamos, New Mexico. New liquid scintillators have been developed with light outputs up to 30% greater than terphenyl-toluene.

A new primary solute is PBD (2-phenyl-5-(4-biphenyl)-1,3,4-oxadiazole). At a concentration of 8 gm/liter in toluene, it gave a pulse height of 121 relative to 3 gm/l PPO in toluene as 100. Other pulse heights measured included PPO (3 gm/l) in xylene, 101; in benzene, 89; terphenyl (5 gm/l) in toluene, 94; BPO (4 gm/l) and PBO (4 gm/l) in toluene, 109 and 121 respectively.

The best plastic was found to be 4% terphenyl, 0.2% diphenylstilbene in polyvinyltoluene, with a relative pulse height of 118.

PBD, used in a plastic scintillator, produced its maximum pulse height at a concentration of 8 gm/l in toluene.

Wavelength shifters that have been developed are shown in Fig. 3 with the wavelength of emission.

The new scintillators give pulse heights comparable to crystals, and they do not have a slow component as do crystals.

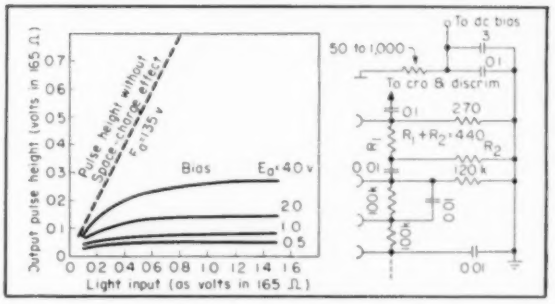


FIG. 4. Circuit and response of 5819 showing space-charge limiting of output (Fischer)

Low-level space charge effects in photomultiplier tubes and some of their applications, by Joachim Fischer, University of Chicago. In time-coincident measurements, large amplitude pulses may cause overloading of following amplifiers. Thus it is desirable to limit the pulse at the photomultiplier. By operating the anode in the region of dynode-10 voltage, space-charge limiting will occur. Characteristics of this limiting depends on input amplitude, and the anode-to-dynode-10 potential difference.

In Fig. 4, the pulse is obtained from dynode-10 of a 5819 photomultiplier. This response is not a perfect limit characteristic, so a network has been added from preceeding dynodes to improve the saturation.

The system has been applied to a fast gate for coincidence with approximately 5 μsec resolution.

Recent experiments at Los Alamos on afterpulsing and cathode resistance effects in photomultipliers, by James S. Allen, University of Illinois, Urbana, Ill.; J. Bergstein, G. H. Best, H. E. Houtz, H. C. Hoyt, and D. W. Mueller, Los Alamos Scientific Laboratory, Los Alamos, New Mexico. The calculations based on positive-ion feedback may possibly explain afterpulsing in 5819 and similar photomultiplier tubes. The afterpulse peaks that occur in the order of ½ and 1 μsec after the main initial pulse could be due to H_2^+ and O^+ respectively. Secondary afterpulse peaks at later times may be due either to ions of higher mass or to a regenerative effect produced by a previous afterpulse peak.

Photomultiplier tubes were connected to an external pumping system; by careful evacuation the afterpulse peaks could be eliminated. Addition of trace amounts of gasses gave times for the afterpulse that depended upon the mass of the atoms. The experimental results when plotted show that the time interval of the afterpulse peak depends inversely on the square root of the voltage applied between cathode and dynode-1. In addition, there is a relation between the amplitude of the afterpulse and this voltage.

In general, it appears that if positive ions are causing most of the afterpulsing, they must start from the region of the first dynode with essentially zero energy, although they may be formed elsewhere in the multiplier structure.

Photomultipliers excited by large amounts of cathode illumination showed effects due to the resistivity of the photocathode material. This is clearly shown when the photocathode is excited with a rectangular light pulse. When the photocathode is excited with a rectangular light

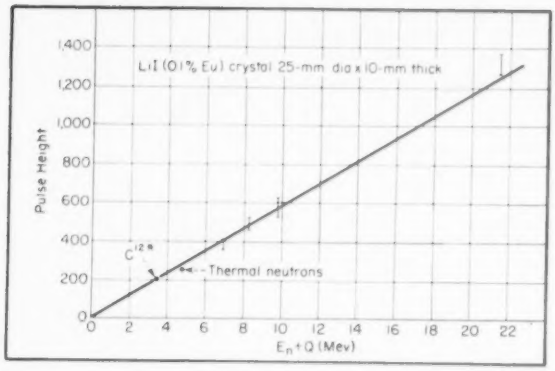


FIG. 5. Response of LiI(Eu) to fast neutrons and gamma rays (Schenck and Neiler)

pulse, afterpulsing appears as an exponentially decaying signal that approaches a limiting value with a time constant of the order of microseconds.

Response of LiI(Eu) to fast neutrons, by James Schenck and John H. Neiler, Oak Ridge National Laboratory, Oak Ridge, Tenn. The field of fast-neutron spectrometry requires the development of scintillators with more efficient fast-neutron response. Using large clear crystals of lithium iodide with different concentrations of europium, pulse-height spectra for incident monoenergetic neutrons were obtained. Figure 5 shows the LiI pulse-height response to gamma and to neutron radiation, respectively. The response to gamma is linear, while the response to neutron radiation is seen to be nonlinear. The two curves were normalized by comparison to a C^{12} neutron peak.

The pulse height from the $Li^6(n,\alpha)$ reaction normalized to gamma response was plotted with respect to Eu concentration; the pulse heights increased as a function of the Eu concentration, finally levelling off at some concentration where the pulse height is above the 4.785 Mev predicted.

The LiI crystal is transparent. However, the Eu causes color centers that can be minimized by heat treatment, with some improvement in pulse height.

In an attempt to clarify the nonlinearity of the neutron response, alpha calibration, gamma calibration, and alpha plus triton data were obtained. The pulse height from the alpha-triton data was larger than could be expected on the basis of the sum of the energy released.

Round-table discussion of photomultipliers and phosphors. Many people reported that they observed pulses of approximately 1,000 electrons, when referred to photocathode, occurring spontaneously from photomultiplier tubes. In counters using a large number of photomultiplier tubes, it was possible to eliminate the effect by using a coincidence technique between two banks of tubes.

A number of hypotheses were put forward. The possibility of the effect being due to neutron bombardment within the photomultiplier tube itself was eliminated due to the number of events occurring, as compared to the neutron flux present. Cerenkov absorption in the glass does not produce enough photons.

C. L. Cowan reported on attempts to introduce high-atomic-number materials into organic scintillators to increase the photoelectric cross section. The first approach was to find a high-atomic-number material both soluble in and compatable to plastic. No conclusive results were obtained.

The second approach was to chemically change the scintillator by addition of mercury into its structure. It was possible to add mercury up to 66% by weight in a polystyrene-terphenyl material. However, it was found that there was clouding in the material due to molding the material, which requires moderate temperatures and causes the scintillation solute to disintegrate. It was possible to make films approximately 500 microns thick. These were evaluated qualitatively and beta response was observable.

George Morton of RCA discussed calculations attempting to explain the enhancement of resolution due to the dynode structure. If a Poissonion distribution is assumed, results do not agree with experimental data. B. Linden of Du Mont and Dr. Morton agreed that a power series would probably be closer to the proper function.

It was pointed out by ORNL personnel that light pipes do not appreciably affect resolution at low energies and do improve the resolution by 2 to 3% at higher energies. Hollow light pipes are not acceptable since there will be surface reflectivity rather than optical coupling. In the case of a large crystal and a small photocathode, light pipes should be as short as possible, rather than long enough to produce a critical angle of reflection at the sides of the cone.

There was general agreement on the gain stability of photomultiplier tubes. A 5819 tube is reported to have operated 24 hours a day for several months in counters with no change in the background counting rate. RCA pointed out that the stability of the silver-magnesium dynodes is superior to that of cesium antimony. However, headlight dimmers, which use cesium antimony, require a reasonable amount of gain stability over very long periods, and good results have so far been obtained.

Photomultiplier tubes (Du Mont 6292) have been used by J. Arnold in carbon-14 measurements for a period of over 14 months with no noticeable change. In connection with gain stability, it was pointed out that sodium iodide has a temperature variation of about 1% for 10°. This effect can be controlled with a small heater in the vicinity of the crystal, which is thermostatically controlled a few degrees above room temperature.

A. Schardt of Brookhaven mentioned the stability of photomultiplier tube noise, that is, in a new tube the noise was low and after a period of 10 min to 1 hr the noise increased. It was agreed that this was probably due to residual gas or charging of the glass. R. W. Engstrom of RCA stated that sometimes tube noise could be reduced by wrapping the tube envelope with a conductor that could be adjusted to approximately the photocathode potential. This will eliminate charging of the glass in the region of the photocathode surface.

Discussion as to whether to use plus or minus high voltage came out a draw. The plus high voltage supply has a possibility of introducing noise from the input capacity. The negative high voltage supply necessitates an outside shield around the photomultiplier tube, connected to the cathode potential, to avoid charging of the glass. In general, the decision as to the type supply to use depends mainly on the high-voltage supply that the individual user has available.

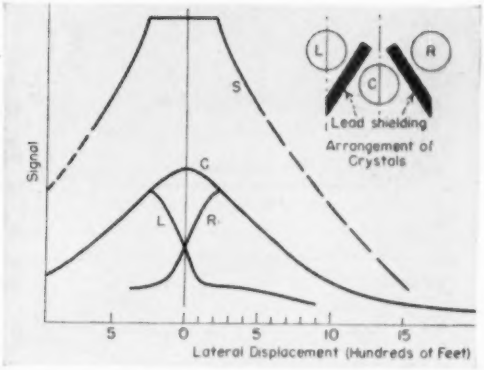


FIG. 1. Sensitivity obtained by lateral displacement of source and with three scintillation detectors shielded as shown at upper right. Aircraft altitude is 600 ft.

Aerial Prospecting with Scintillation Counters

This system, suitable for locating radioactive ores in rough terrain, uses:

- **Two unshielded detectors and ratemeter with cancellation circuit**
- **Continuously recording radioaltimeter**
- **Continuously running aerial camera**
- **Coding system for synchronizing the three records**

By G. COWPER
Atomic Energy of Canada Ltd.
Chalk River, Ontario, Canada

AERIAL PROSPECTING for radioactive minerals is practicable when a number of conditions are satisfied. These are:

1. A sufficient fraction of the mineral deposits is exposed to the surface.

2. The gamma radiation detector is sufficiently sensitive to record unambiguously a significant change in the ground radioactivity from an altitude governed by aircraft safety.

3. The total weight of detecting equipment is small enough to permit use of a small aircraft, making this method economically sound.

To meet conditions 2 and 3, a practical airborne detector using scintillation counters was developed at Chalk River in 1950.

Experiments had been done in the previous two years using high-pressure argon-filled ionization chambers and multiple Geiger-counter assemblies.

The ionization chambers suffered the disadvantage of being sensitive not only to the number of ionizing events occurring, but also to the amount of ionization associated with each event, so that cosmic radiation produced a disproportionately large signal serving only to obscure the identification of gamma radiation from the ground. Geiger counters suffer a similar disadvantage in that they have an efficiency for cosmic ray detection that is about 100 times that for gamma radiation. However, by using a large bundle of Geiger counters with suitable anti-coincidence circuits, this condition can largely be overcome. There still remains, however, the fact that Geiger counters are inefficient detectors of gamma radiation. G-M tubes having a multiple-plate cathode structure provide some improvement in counter efficiency; however, this requires a very elaborate constructional technique. It was therefore decided to use a scintillation detector.

Aircraft

There are many desirable features about using a helicopter, since it has great flexibility of movement coupled with a high degree of safety at low altitude. The course of a survey can be changed very easily, and it is a simple matter to land at interesting locations and collect mineral samples.

However, there are certain disadvantages to using a helicopter that appeared uppermost when the particular type of territory to be examined in Canada was considered. Since the operations were to be carried out in completely unpopulated country, it was necessary that the aircraft should be capable of operating from one of the few available airfields and not be dependent upon other transportation systems to bring in normal running supplies.

Furthermore, it was essential that the aircraft should have a sufficient range to enable it to spend a useful fraction of its time over the area to be surveyed. In addition, there was a requirement to cover a very large area of ground in a reasonable time, making only a statistical sample of the radioactivity; this would lead to further investigation of the areas of greatest interest. Thus, the aircraft would fly a grid pattern at about ½-mile intervals, covering strips of ground only

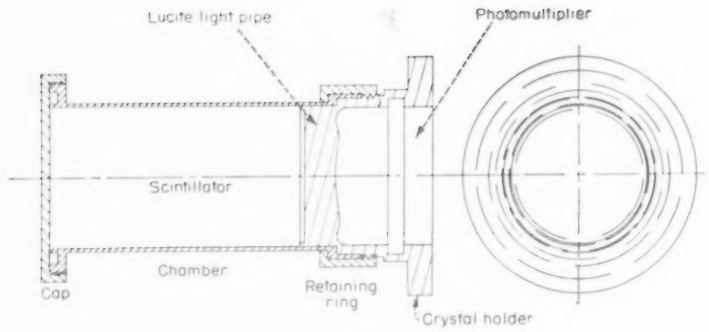


FIG. 2. Crystal units contain two 2 × 2 in. NaI(Tl) crystals

a few hundred feet wide. A helicopter therefore was not used.

Aircraft selected. Two aircraft were used—at first an Anson V and later a Beechcraft Expeditor, chosen because of its superior performance on one engine at low altitude.

Apart from the addition of extra gasoline storage space, the only major modification to the aircraft was the removal of all radioactive fluorescent visual aids from the aircraft instruments and appliances. These were replaced by nonradioactive phosphors made luminous by ultraviolet light.

Detection Apparatus

The first scintillation survey apparatus consisted of three large thallium-activated sodium iodide crystals, together with three end-window photomultipliers mounted as shown in Fig. 1. Lead plates were placed to reduce the sensitivity of the outside counters in certain directions.

The sensitivity pattern is shown in Fig. 1. A source of radiation is moved in a direction normal to the axis of the crystal assembly, which lies along the line of flight of the aircraft, and the measured counting rates are plotted against this lateral displacement for each crystal and for the sum. Thus it would appear that, by examination of the relative counting rates from the side crystals, one could determine the approximate disposition of a radioactive deposit. Furthermore, there should be an indication of whether the radiation received is from a point source or from an extensive area. However, while this is undoubtedly true if the territory to be surveyed is flat for distances large compared with the altitude of the aircraft, in the Canadian territory of interest one is frequently flying over narrow valleys where the slant distance to a hilltop is comparable to the height above the valley.

It was found that the usefulness of the lead shielding was not great. In later models a much simpler arrangement was adopted. Not only did this change save the weight of the lead shielding, but in addition there was now only required one ratemeter instead of three, and the photomultiplier crystal assemblies were now built into one unit. The trials of the first equipment had shown that there was no lack of sensitivity; since the lead shielding reduced the efficiency of the outer counters, it was decided to use in the subsequent models only two counters that were unshielded.

Scintillators. The crystal units each contain two thallium-activated sodium iodide crystals 2 in. in diameter and 2 in. long, placed end to end (Fig. 2). They are surrounded by shiny aluminum foil and placed in an aluminum can from which all the remaining air is

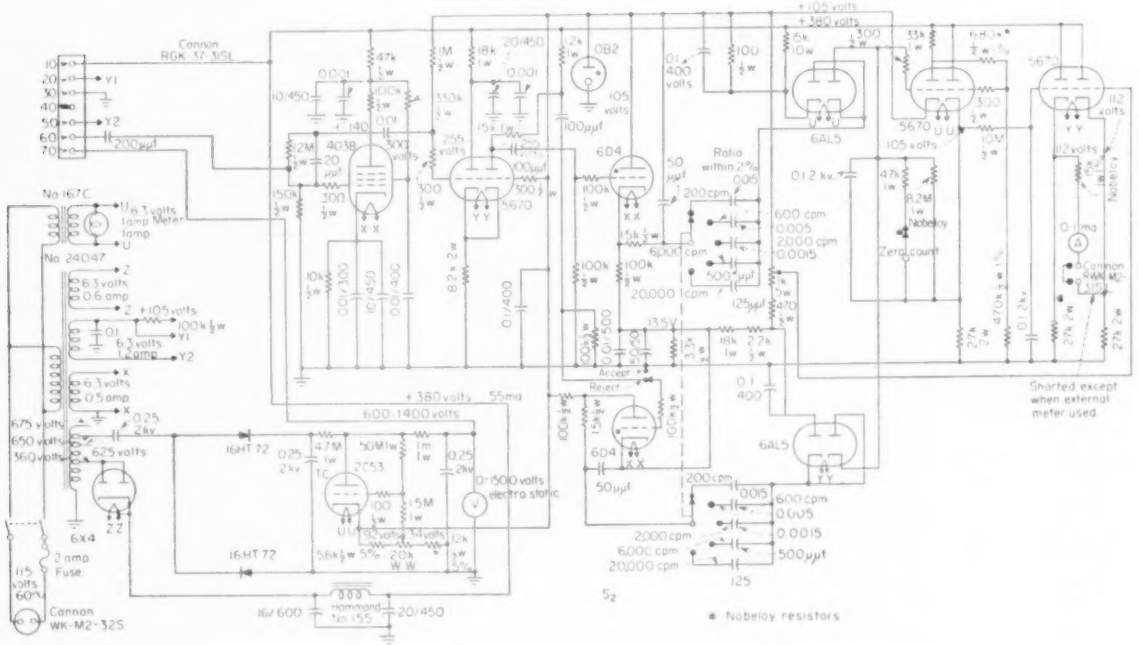


FIG. 3. Circuit of ratemeter and power supply

displaced with silicone oil. A Lucite end cap on the cylinder, which fits over the end of the photomultiplier, permits the scintillations to reach the photocathode.

The pulse outputs from the two photomultipliers are added and fed into a cathode-follower stage mounted in the same unit. Connection is made through several feet of cable to the second unit containing the counting-rate meter and power supplies. The rate meter output is recorded continuously on a recording milliammeter. Provision is made for separate adjustment of the photomultiplier voltages, and they may be operated singly so that the sensitivities from each counter can be made equal.

Cosmic radiation. The counting-rate meter (Fig. 3) is of conventional design based upon a laboratory health monitor with a modified integrating circuit and with an additional circuit that cancels out the contribution from large cosmic ray pulses.

In the volume of crystal used in the prospecting apparatus, the contribution by cosmic radiation amounts to about 150 cpm at sea level. It was decided to eliminate these pulses by a simple cancellation circuit.

Pulses from the photomultipliers are passed through one stage of amplification in the ratemeter (Fig. 3) and are then presented to two ratemeter circuits having sensitivities differing by a ratio of 15:1. The large cosmic-ray pulses trigger both ratemeter circuits while the γ-ray pulses trigger only the more sensitive circuit. The two channels are combined at the storage capacitor so that large pulses simultaneously add and subtract equal charges to and from the storage capacitor. The smaller γ-ray pulses cause only an increase of charge in the capacitor.

A switch permitting elimination of this cosmic-ray rejection circuit is used in setting up the equipment. The photomultiplier voltages are raised until the counting rate from a radium source is just reduced by a few per cent when the rejection circuit is added.

Full-scale sensitivity of the ratemeter is adjustable, but in practice the 0–6,000 cpm range has been found suitable. In an uncontaminated aircraft the background count over water was approximately 1,000 cpm.

Detector response. Consider the idealized case of a point source of radioactivity surrounded by a large nonactive area (in trials this situation can be realized by placing a radium source on a small island in a large lake.) Then, as the aircraft is flown over this source, the rate meter output shows a characteristic pattern (Fig. 4, calculated curve) described by

$$F(t) = \frac{I_0 e^{-\mu\sqrt{v^2t^2 + h^2}}}{v^2t^2 + h^2} \qquad (1)$$

where μ is the effective γ-ray absorption of air, v is the velocity of the aircraft, and h is its altitude; the denominator is the square of the slant range of the aircraft from the source as it varies with time.

This is the characteristic response of the equipment and is theoretically easily identified. In practice, however, superimposed upon this are fluctuations caused by poor statistics from small counting rates as well as radiations from competing sources that are independent of the movement of the aircraft, such as local contamination. Wiener* found in radar work that for optimum intelligibility the transmitted pulse should have a shape

$$F(t) = Ae(-t^2/2\beta) \qquad (2)$$

This Gaussian curve is very similar to the curve of Eq. 1 and can be fitted over a considerable region.

The optimum frequency response found by Wiener for the detector is

$$F(w) = Be^{-\beta w^2}$$

Such a detector would give maximum signal-to-fluctuation ratio, but signal arrival would be infinitely delayed.

It may be shown that in the limit

$$Be^{-\beta w^2} = L_{n\to\infty}\ (\text{const.})\ \frac{1}{\{(1/\sqrt{4\pi\beta})(n!/n^n e^{-n}) + iw\}^n}$$

which is the Fourier transform for the response of n independent low-pass resistance-capacitance filters connected in series. A good approximation to the ideal response, with reasonable delay in response, is obtained with two equal independent low-pass filters in series. For the case of an aircraft flying at an altitude of 500 ft and at 200 ft/sec, a suitable value of time constant is 0.8 sec; this yields a delay time of 2 sec. The improvement obtained with the double filter is shown in Fig. 5.

Altitude. The prospecting aircraft carries a radioaltimeter, whose output is recorded continuously, and a continuously running aerial camera. A synchronized coding system puts simultaneous marks on all three records, which are numbered in sequence and written down on the navigator's chart.

Interpreting Results

The extent of the radioactive deposits is interpreted by a detailed comparison of counting rate, altitude and

* N. Wiener, OSRD-370 (1942).

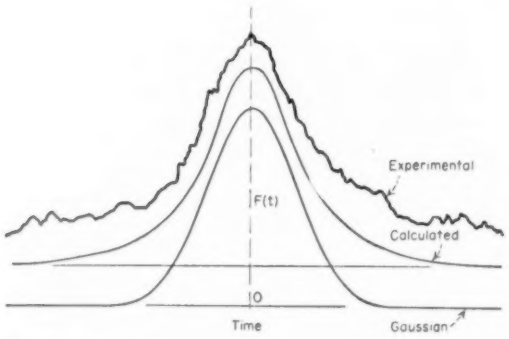


FIG. 4. Detector response to point source surrounded by nonradioactive area

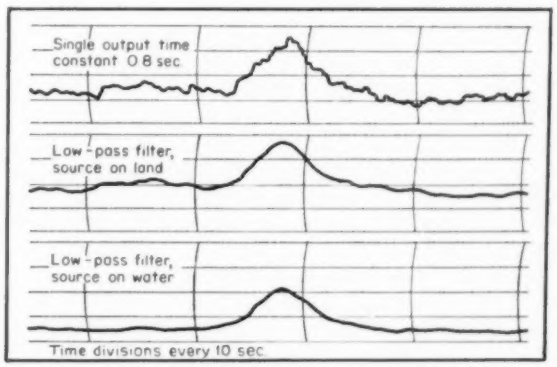

Single output time constant 0.8 sec
Low-pass filter, source on land
Low-pass filter, source on water
Time divisions every 10 sec

FIG. 5. Improvement in detector response obtained with two equal independent low-pass filters in series

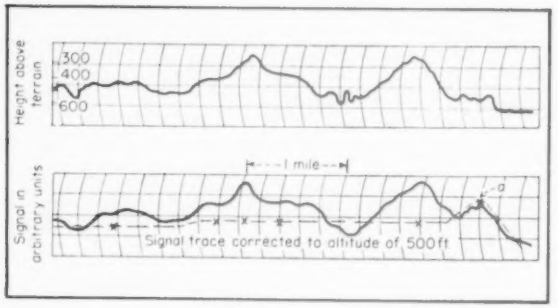


FIG. 6. Correction of signal trace for altitude variations

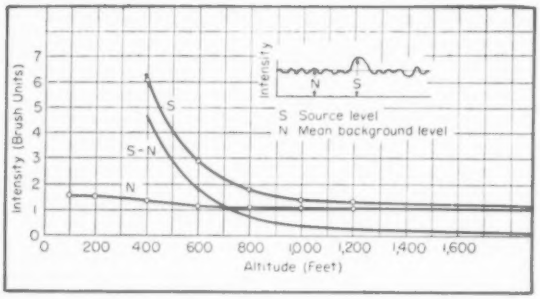


FIG. 7. Sensitivity of scintillation counter; 88-mc Ra source placed in center of frozen lake

photographs of the ground. Because of the rugged country surveyed, a correction factor has to be applied to the counting rate record to normalize the radiation intensity to constant altitude in order that the real activities of the various deposits can be compared.

When the aircraft is travelling in level flight, it passes over, at different altitudes, terrain whose nature is changing rapidly with time. This includes lakes, swamp, thinly covered rock and completely exposed rock on hilltops. Since there is a small concentration of radioactive material in nearly all rock structure, the detector records a continuously changing activity depending upon the proximity of the rock and the extent to which it is covered by topsoil and other nonradioactive material. In many instances, this worthless activity gives a signal comparable to that from a valuable ore body. It is equally true that a valuable ore body that is almost completely covered by nonradioactive overburden gives a signal that may be overlooked.

It should be possible to provide an automatic correction by coupling a signal derived from the altimeter output to the ratemeter circuit that would smooth out pulse responses due to proximity effects. However, detailed analysis of surveys made showed that it was not possible to choose a simple signal-to-height relationship that would take care of all possible cases of ground conditions. Instead, during the course of field operations when results were required immediately, a simple correction was made. A new signal trace was drawn on the recording in which the counting rate response was corrected roughly in fixed proportion to the inverse of the height as given by the radioaltimeter.

The constant of proportionality was determined empirically from examination of the counting-rate meter and altimeter readings. When this correction was applied to a section of the record before and after a suspected area, and it substantially reduced the fluctuations, it was then applied also to the suspected portion. If a significant signal remained after correction, then this was considered to indicate a true anomaly. A sample of this adjustment is shown in Fig. 6.

Location of high-grade ore. The remaining problem in interpretation of results, and the most difficult to solve, is to provide a detector capable of distinguishing between localized outcrops of high grade ore and large areas of slightly abnormal radioactivity. So long as the aircraft flies at the present altitude of 500–600 ft and at a speed of 200 ft/sec, it is not possible without seriously reducing the sensitivity of the apparatus to restrict the area of ground seen at any instant. If the acceptance angle of the detector is restricted only in the line of flight, no increase in detector sensitivity or speed of response is required, but a number of additional detectors are now needed to cover the same area of ground unless a much more closely spaced flight plan is adopted. Alternatively, if the acceptance angle is unrestricted in the sideways direction, no additional detectors are required to cover the same ground; however, since the time the detector sees the ground is now severely limited, the time constant of the ratemeter must be drastically reduced. With no further increase in sensitivity, statistical fluctuations in the background, which are now greater, tend to mask significant changes in counting rate.

However, if no limit is set on the weight of the apparatus, such a directional equipment is entirely feasible, and the angle of acceptance can be restricted in both directions with the losses in sensitivity incurred being taken up by the multiplication of the numbers of the detectors. This was not done.

Also, further investigation of the possibility of discriminating between localized and extensive deposits by carrying out a survey at two different heights should be made. One attractive way of doing this would be to tow a second detector on a cable some 200 ft below the aircraft.

An indication of the sensitivity of the apparatus is given in Fig. 7. An 88-mc radium source was placed on the center of a large frozen lake. Level flights were made over it at different altitudes. The maximum measured counting rate from the source, as well as the difference between this value and the mean background level, is plotted against altitude.

A field survey was made over an area that had been well mapped by ground parties and was known to contain 20 natural pitch-blend deposits. A study of the aerial records revealed 21 anomalies, 20 corresponding to the known ground deposits. The missing deposit was found later by a ground party.

Flights were made over the same area at different altitudes to determine the optimum survey altitude. At 700 ft it was found that none of the deposits gave a signal that was significantly different from background; at 550 ft all deposits could be easily identified.

* * *

This article is based on a paper presented at the Scintillation Counter Symposium, Washington, D. C., January 27, 1954. The work, first reported as CRR-495, was carried out by H. Carmichael, J. F. Steljes and the author, of the Chalk River laboratories, and by G. S. Levy, S. H. G. Connock and E. A. Godby of the Flight Research Section of the National Research Council.

General Applications

D-C ratemeter techniques applied to scintillation counters, by H. D. LeVine, New York Operations Office, U. S. Atomic Energy Commission, New York, N. Y. In addition to logarithmic circuits (NU, Feb '54, p. 36), linear circuits have been developed that use a 5886 triode in an electrometer circuit. This circuit is used with a 12-stage, 3-in. diameter Du Mont photomultiplier and a 2-in.-thick crystal in a 10-lb aerial surveying instrument. A 1-ma recorder can be driven directly. A 10× range is obtained by changing one resistor in the circuit.

Application of scintillation counters in radiobiology, by A. Krebs, W. Parr, and S. Bush, U. S. Army Medical Research Laboratory, Fort Knox, Ky. In radiobiology, use of the scintillation counter has been concerned with (1) efforts to develop air-equivalent scintillation phosphors for *in vivo* dose measurements with beta and gamma emitters and for the establishment of a universal physical dose unit valid for all ionizing radiations and (2) studies of energy transport and energy migration mechanisms in irradiated biological systems.

Work has been started to study the performance of polycrystalline scintillators. *In vivo* measurements are made inside the body in close proximity to beta and gamma emitting isotopes.

Closely related to the mechanism of biological radiation effects are studies of the luminescence of biological compounds under bombardment of high-energy radiation. The experimental set-up, by means of the sample changer, allows comparative measurements of solvent and solution. Results are given in Table 1. All solutions show a lower luminescence efficiency than the solvent.

Concentration studies with tryptophane, ascorbic acid, and nucleic acid showed that with increasing concentration the luminescence decreases in all cases. A formal quenching constant could be easily calculated with the Stern-Volmer formula, but it seems desirable to study first in more detail the Cerenkov radiation conditions.

Since in total-body irradiations biological compounds are influenced, the effects of 50-kv X-rays on their luminescence were studied. With increasing dose, the luminescence of tryptophane was decreased and that of ascorbic acid was increased, in each case reaching a saturation value. Thus, all solute molecules were apparently decomposed. Comparison of the luminescence efficiency curves with the decomposition curves indicates that the decomposition products contribute more than anticipated to the effects of ionizing radiation.

Chlorophyll, exposed to 50-kv X-rays, shows a decrease of luminescence in alcohol solution and an increase in water suspension. Studies of irradiation of riboflavin solution with 50-kv X-rays show a decreasing luminescence with increasing concentration and increasing luminescence with increasing dose. Riboflavin is decomposed into lumichrom and/or lumifer, and the observed changes may be

TABLE 1—Luminescence of Aqueous Solutions under Co^{60} Gamma Bombardment (Krebs, Parr and Bush)

Solute (1 mg/ml)	*Solvent*	*Concentration*	*Relative luminescence**
Amino acids			
Glycine	Neutral	1 mg/ml	94
L-cystine	Neutral	1 mg/ml	93
Cysteine (HCl)	Neutral	1 mg/ml	87
DL-phenylal.	Neutral	1 mg/ml	83
L-phenylal.	Neutral	1 mg/ml	79
DL-tryptoph.	Neutral	1 mg/ml	69
L-tryptoph.	Neutral	1 mg/ml	59
Nucleic acids			
Adenylic acid	Neutral	1 mg/ml	66
Hypoxanthine	Neutral	1 mg/ml	64
Cytosine	Neutral	1 mg/ml	61
RNA	Neutral	1 mg/ml	59
DNA	Neutral	1 mg/ml	58
Thymine	Neutral	1 mg/ml	56
Uric acid	Neutral	1 mg/ml	54
Enzymes			
Rennin	Neutral	1 mg/ml	92
β-amylase	Neutral	1 mg/ml	85
Mylase P	Neutral	1 mg/ml	78
Urease	Neutral	1 mg/ml	66
α-amylase	Neutral	1 mg/ml	65
Hormones			
Estrone	Neutral	1 mg/ml	100
Progesterone	Neutral	1 mg/ml	95
Proteins			
Human albumin	Neutral	0.1 sol.	81
Human γ-globulin	Neutral	0.1 sol.	80
40% γ-globulin + 60% albumin	Neutral	0.1 sol.	79
Vitamins			
Riboflavin	Alkaline	0.1 mg/ml	30
	Alkaline	0.01 mg/ml	72
	Acid	0.1 mg/ml	33
	Acid	0.01 mg/ml	78
Ascorbic acid	0.25% oxalic acid	0.1 mg/ml	90
	0.25% oxalic acid	0.01 mg/ml	94
	Dist. H_2O	0.1 mg/ml	76
	Dist. H_2O	0.01 mg/ml	98
Nicotinamide	Dist. H_2O	0.1 mg/ml	70
	Dist. H_2O	0.01 mg/ml	89

* Relative luminescence based on 100 for pure solvent.

caused by the production of these substances. A chemoluminescence may also be responsible for the increase in luminescence efficiency.

With the increasing complexity of the biological systems studied, the situation becomes very complicated. Multisolute systems are characterized by adsorption phenomena, structural differences and differences in state.

Applications and requirements of scintillation counters for medical radioisotope laboratories, by Theodore Fields, V. A. Hospital, Hines, Ill. The common problems underlying all routine clinical radioisotope tests, as far as instrument operation is concerned, are: nonelectronic-minded operating personnel (generally medical technicians, nurses, M.D.'s); extreme line-voltage fluctuations (90–115 volts often observed); economy of time and money; and acceptable accuracy of ±2%. Instruments suggested in Table 2 satisfy these requirements for certain tests.

Many of the tests can be performed with the same type of counter if their characteristics are similar. Scintillation counters aid considerably in reducing the radiological exposure hazard inherent in performing these tests.

Future improvements in construction features, operating characteristics, and reliability will eliminate the need for a physicist with each medical scintillation counter.

Chemical element analysis of radioactive mixtures in biological materials, by Theodore A. Hall, Sloan-Kettering Institute for Cancer Research, New York, N. Y. Applications of scintillation-counter techniques to double-tracer and neutron-activation problems indicate that radioactive mixtures can be analyzed without chemical separation.

The mixture is regarded as a linear combination of the isotopes in the mixture. Simultaneous equations obtained by comparing the mixture and standards can be solved for all the combination coefficients.

In the double-tracer study, the selective uptake of a serum mixture in various tissues of a tumor-bearing animal was measured. The mixture consisted of a serum (c) containing special protein labeled with cyclotron-produced iodine isotopes (a) and control serum (p) labeled with pile-produced I^{131}. In a test run made (Table 3), counting rates for pure label and mixture vials are C, P and M; coefficient of combination is k. For pulse ranges 1 and 2, $M_1 = k_c C_1 + k_p P_1$ and $M_2 = k_c C_2 + k_p P_2$. The quantity $k_c/k_p = (M_1P_2 - M_2P_1)/(M_2C_1 - M_1C_2)$ expresses the ratio of the activities of two labels in any mixture M.

TABLE 3—Test-Run Iodine Double Tracer (Hall)

	Counts	
*Vial**	*0.2–0.4 Mev pulse range*	*0.5–1.2 Mev pulse range*
p	120,554	5,389
c	98,422	73,251
1	109,506	39,380
2	116,046	23,427
none	137	91

	Results			
Vial	k_c *(calc.)*	k_c *(nom.)*	k_p *(calc.)*	k_p *(nom.)*
1	0.500	0.500	0.493	0.500
2	0.260	0.250	0.746	0.750

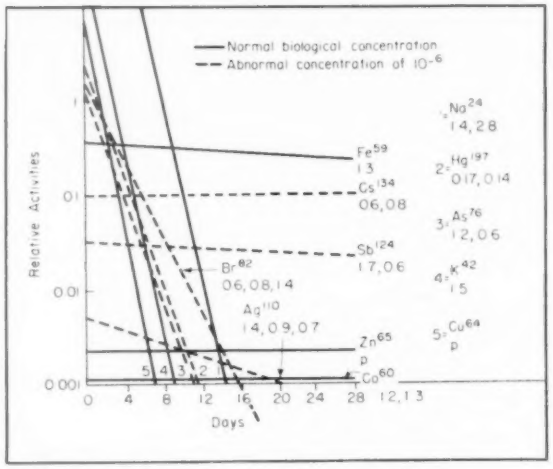
* Vial p contains pure pile-produced label, c contains pure cyclotron-produced label, and 1 and 2 are mock-up vials.

Materials in small vials were counted in a 1½ × 2 in. NaI well. With a single-channel analyzer, data were taken in two pulse-height ranges, to accentuate one label and then the other; ranges should be as wide as possible to maximize counting rates.

Table 4 shows data obtained with a tumor-bearing animal.

TABLE 2—Some Routine Clinical Radioisotope Tests and Characteristics of Applicable Scintillation Counters (Fields)

				Test data		
Clinical test	*Isotope*	*Dose (μc)*	*Administration*	*Concentration range*	*Instrument time/test*	*Readings per patient*
Thyroid state evaluation	NaI^{131}	50	Oral	(samples measured) Thyroid: 1–50 μc, blood: 10^{-5}–10^{-3} μc/cm³, urine: 6×10^{-5}–0.1 μc/cm³	(Maximum) Thyroid: 10 min, blood: 15 min, urine: 15 min	(24 hr after dose) 6
Uptake Blood and urine						
Brain tumor localization	NaI^{131} or I^{131} HSA	350	Oral or intravenous	(in vivo) 0.003 μc/gm normal brain or 4.5 μc total in brain	1–1½ hr	40
Fluid volume	I^{131} HSA	5	Injection into closed space	(in vivo) 10^{-3}–10^{-2} μc/gm	10–15 min	2 or 3
Semiroutine tests						
Metabolism	Fe^{59}	25		10^{-4} μc/cm³	15 min	
Cell mass	Cr^{51}	50		0.01 μc/cm³	15 min	
Clearance	Na^{24}	100		0.02 μc/cm³	5 min	
Cardiac	I^{131}	1.0		0.1 μc/cm³ (total)	2 min	
Brain	P^{32}	200		2×10^{-4} μc/cm³	15 min	



DECAY of radioisotopes in biological material (Hall)

In neutron-activation studies, the material to be analyzed is placed in a pile, along with pure samples of its constituents. The products are measured by simultaneous pulse-height and coincidence analysis, using two $2 \times 1\frac{1}{2}$ in. crystals and a coincidence analyzer modified for two a-c channels.

The formulation for coincidence analysis is

$$S_M = k_a S'_a + k_b S'_b + \ldots + S_B$$
$$C_B = C'_B + S_B{}^2 t$$
$$C_a = C'_a + C'_B + S_a{}^2 t$$
$$C_M = k_a C'_a + k_b C'_b + \ldots + C'_B + S_M{}^2 t$$

where $a, b, c, \ldots$ are constituents of the mixture M, S_a = (geometrical) average counting rate in one crystal (no coincidence) for the vial containing pure element a, $S'_a = S_a - S_B$ with B denoting background. C = coincidence rate, C' = single-event coincidence rate, t = coincidence interval, and k_a = ratio of a in the mixture to a in the pure standard.

TABLE 4—Biopsy Measurement, Iodine Double-Tracer Experiment (Hall)

Material	k_c/k_p	*Material*	k_c/k_p	k_c/*mass*
Injection	1.32	Tumor†	0.96	0.47
Blood*	0.99	Breast†	1.08	0.12
Blood†	0.96	Breast†	0.97	0.13
		Skin	0.95	0.81

*Counted 15 min after injection. †Counted 1 day after injection.

TABLE 5—Test Run "Biological" Mixture of Fe, Zn and Co (Hall)

		0.8–1.4 Mev		*0.3–0.55 Mev*		
Vial	*Activity (μc)*	*Single cps*	*Coincident cps*	*Single cps*	*Coincident cps*	*Measured k*
None			0	15.6	0.06	
Fe	0.3			275	0.606	0.32
Zn	0.03			34.7	0.618	0.38
Co	0.0006		0.119	16.7	0.08	0.38
Mixture	0.1 Fe + 0.01 Zn + 0.0002 Co	188	0.062	105.6	0.448	

The figure shows that Fe, Co, Zn, Na, K and Cu should be measurable in normal biological material and Sb, Ag, Br, Cs, Hg and As when present at 10^{-6} gm/cm³.

Results are given in Table 5 for a mock-up mixture of Fe, Zn and Co, simulating 1 gm of normal tissue after 30 days pile irradiation and 30 days cooling; running time was 3 hr and $t = 0.45$ μsec.

In the discussion, it was mentioned that neutron studies are expected to be made with the Brookhaven reactor.

Scintillation counter requirements

Counter type	*Phosphor material*	*Phosphor dimensions (in.)*	*Geometrical efficiency*	*Flux/min (minimum)*	*Background/min (maximum)*	*Discrimination bias (Mev)*	*Secondary radiation filter*
Scanning	NaI(Tl)	$1\frac{1}{2} \times 1\frac{1}{2}$	4×10^{-4}	880	450	0.363	2.8 gm/cm²
Well	NaI(Tl)	2×2	1	132	250	0.363	none
Scanning	NaI(Tl)	$1 \times 1\frac{1}{2}$ Th.	170×10^{-4}	10,000	1,000	0.363	2.8 gm/cm²
Well	NaI(Tl)	2×2	1	2,000	300	0.363	none
Well		2×2	1	200	150		
Well		2×2	1	2,000	300		
Scanning		$1 \times 1\frac{1}{2}$	0.014	500	200		
Scanning		$1 \times 1\frac{1}{2}$	0.014	3×10^4	1,200		
Needle		$\frac{1}{8} \times \frac{1}{2}$	1	500	250		

Large Scintillators, Cerenkov Counters for High Energies

Shower data from measurements of C, Al, Cu, Sn, and Pb are used to estimate the size of counter needed to obtain narrow pulse-height distributions in useful scintillation materials. It is possible to extend the "total absorption" spectrometer principle to higher energies, and Cerenkov counters can be used

By ASHER KANTZ and ROBERT HOFSTADTER
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THE IDEA OF USING large scintillation or Cerenkov counters for high-energy spectrometry is so attractive that we have endeavored to study the fundamental process of energy loss in electromagnetic showers in various materials. Thus, basic questions governing detector size can be settled at the outset. This article is concerned with such basic measurements and the conclusions drawn from such measurements.

Why Instrument is Needed

Many experiments in the field of high-energy physics require measurement of the number of energetic quanta or electrons passing through a given area in a given time. Suitable detectors for such events have generally been magnetic spectrometers of one kind or another. Perhaps the best known is the so-called "pair spectrometer" whose operation is based on the measurement of the momentum (or energy) of each of the positive and negative electrons arising in the pair-production process by gamma rays. A simple magnetic spectrometer suffices for the measurement of the energy of a single electron or positron.

While such basic magnetic instruments are best employed for absolute measurements and calibration techniques, high energies require very large radii of curvature and therefore long magnetic paths. Such large magnets are obviously inconvenient for many purposes and also prove to be very costly in iron, copper and power. For example, a 1.0-Bev electron has a bending radius of 7.3 ft in a magnetic field of approximately 15,000 gauss. If a 30 degree deflection is employed in a double-focusing magnet, a solid angle of only 3.5×10^{-3} steradians is obtained for a cross sectional area through the magnet of 0.25 ft^2. A 30 degree magnet of this type will weigh approximately 10 tons. If a 180 degree bend is employed, the solid angle becomes approximately 6.5 times larger and the weight becomes about 60 tons.

This situation is both typical and fundamental, since any bending device to be used in measuring gamma rays will employ a magnet for electrons (or positrons). At higher energies the bending radius goes up proportionally with the energy, and for a given solid angle of detection the weight will go approximately with the cube of the energy. For 10 or 100 Bev the costs and sizes involved become very great indeed. Possibly strong focusing devices may alleviate this situation.

Evidently it would be desirable to have a measuring device whose size and weight are not proportional to the cube of the energy, at least in the energy range considered. Putting the statement more positively: it would be desirable to have a small and geometrically flexible instrument to study high-energy gamma-ray and electron energies. Fortunately there seems to be a possible solution answering these needs. It is the large-scale scintillation (or Cerenkov) counter. This device has sometimes been called a "total absorption" spectrometer. This name has been used particularly at lower energies (1–10 Mev).

The mode of operation of this type of spectrometer is extremely simple and the principle rather obvious. The electron or gamma ray* is allowed to strike a large crystal or other type of luminescent material such as a liquid scintillator or Cerenkov material. In so doing the electron develops a "cascade electromagnetic shower" consisting of electrons, positrons and gamma rays, all of which are eventually degraded into low energy (1.0 ev–1.0 Mev) electrons or positrons. The sum total of the light produced in the crystal by each of the degraded electrons or positrons may be measured in the usual way by a photomultiplier.

If the entire shower is absorbed in the crystal the energy of the shower

* Henceforth we shall speak only of electrons, since gamma measuring devices reduce ultimately to electron devices.

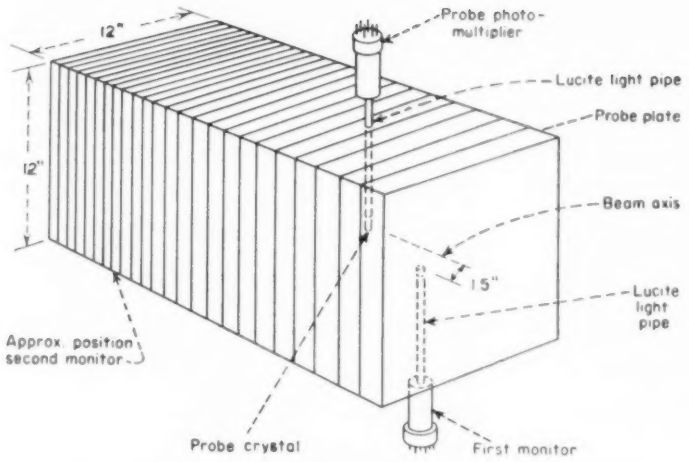


FIG. 1. Apparatus used in making shower measurements

(and hence the energy of the original particle) will be proportional to the total amount of light produced. The height of the pulse emerging from the photomultiplier may then be expected to be proportional to the original energy of the particle. In other words, by transforming the kinetic energy of the particle into that of a great many less energetic particles of smaller penetrating power, the whole energy of the particle may be retained in a relatively small volume (crystal) and there examined by virtue of the light produced. In practice the crystal will be buried in a shield carrying an opening in one end for entrance of the incident particles.

At the present moment the method proposed has been essentially untried for purely practical reasons: (a) large crystals have been relatively unavailable, (b) large volumes of liquids are either not dense enough or very costly, (c) large transparent specimens of successful Cerenkov materials, while possible in principle, have not been produced, (d) large photomultipliers have only recently been developed and are becoming available, (e) the methods of collecting light from large counting volumes have not been developed in an economic way.

But the idea is still attractive enough to warrant investigation. We have carried out measurements with electrons from the Stanford University linear accelerator at an energy of 185 Mev. While electrons of higher energies will be available in the near future, these results should be representative of the present energy ranges in greatest use. Moreover, the depth of crystal material needed for higher energies varies only as the logarithm of the primary energy (*1*) and the linear dimensions do not increase, as with a magnetic spectrometer, in proportion to the energy itself. Thus to capture 90% of the total energy of a primary electron of 185 Mev in NaI(Tl), the crystal would have to be approximately 10 inches long and 10 inches in diameter. A 10-Bev crystal should be only four times as long and probably not as large as four times the diameter. The 10-Bev crystal will, of course, serve for all lower energies.

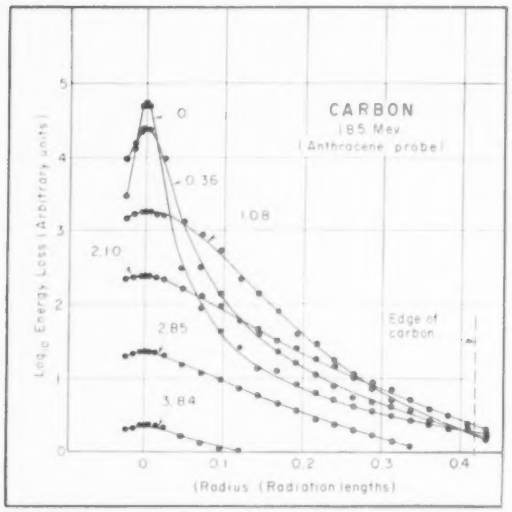
Method and Results

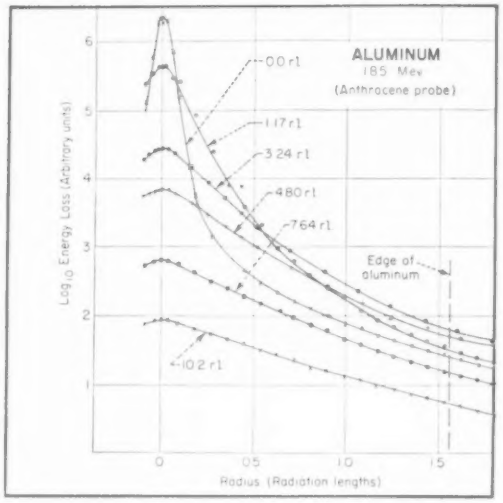
The primary question is "How much energy is lost in each volume element of a given absorbing crystal or liquid?" The most useful and practical crystals or liquids are not simple elements of the periodic system. However, the data for a useful material can be obtained easily by composition of the results for its elemental components. Hence an investigation of a representative group of elements will suffice for most common scintillators, particularly since the shower characteristics do not vary rapidly with atomic number. In some cases, for example, anthracene or NaI(Tl), the scintillator may be fairly well approximated by its chief constituent, e.g., carbon or iodine respectively.

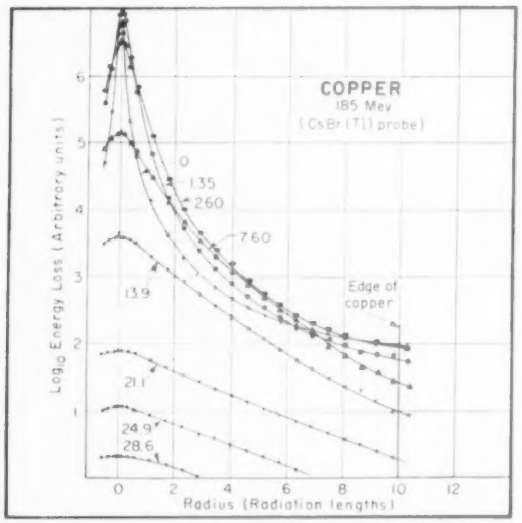
Confining our attention therefore to elements alone, we shall study the following representative ones: carbon, aluminum, copper, tin and lead. The experimental technique employed is practically identical with that reported in a previous investigation of electron-induced showers in copper (*2*). For these elements, Fig. 1, we have placed a scintillation-counter probe of small size into a cylindrical cavity bored in a plate of the material investigated. This so-called "probe plate" is one of a set of many plates of the material studied. These plates are stacked serially so that the probe plate be interchanged with any individual plate.

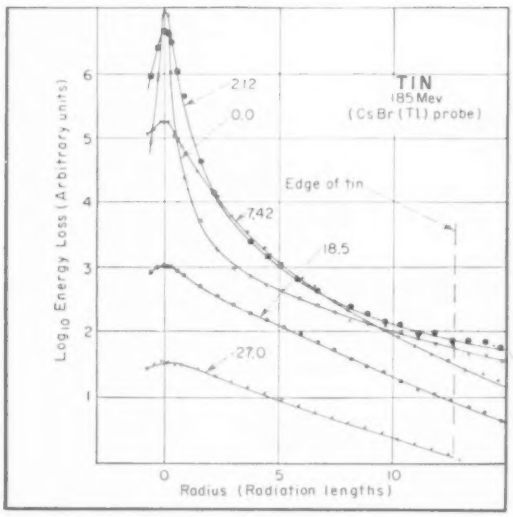
Figure 1 also shows the light pipe that carries the light emitted by the probe to the photomultiplier. A d-c amplifier connects the photomultiplier output to the input terminals of automatic recording equipment. Two monitors buried in separate monitor plates keep a record of the primary electron beam intensity at all times. The probe data are taken simultaneously with the monitor data and all are recorded automatically. The normalized probe data are obtained finally by forming the ratio of the probe and monitor readings. Any contribution of Cerenkov radiation in the light pipe is always subtracted out (*2*).

The basic data are obtained from the so-called "radial curves." Such curves represent the ratio of probe reading to monitor reading at various radial positions in a definite plate at a given depth in the pile. Figure 2 show the data obtained in radial runs. Figure 3 shows the radial runs observed in air without the pile plates in position. The test runs of Fig. 3 were taken to show that the radial spreads are not due to the original beam divergence, but to an actual spread of the beam by shower production. For each material studied, a specially chosen probe material was employed. The aim has been to make the probe simulate (or be identical with) the material investigated so that it does not show "contrast" with the material. Probe materials are also selected with an eye towards the slowness of decay of their luminescence; the pulsed nature of the electron beam is responsible for a choice of "slow" scintillators to avoid space-charge saturation in the photomulti-









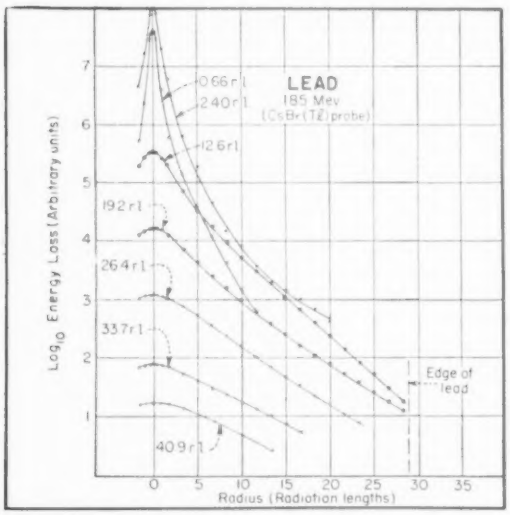


FIG. 2. Radial curves at 185 Mev. Numerals attached to curves indicate depth of probe plate in radiation lengths. Zero depth means just in front of the pile. For lead, probe crystal was cylinder of diameter 0.125 in. and thickness 0.1 in. For all other materials, probe crystal was cylinder of diameter 0.25 in. and thickness 0.125 in.

plier. A more complete discussion of the problem of probe choice is given in reference (2).

We have measured all lengths in this paper in terms of a unit called a "radiation length." This unit is commonly employed in shower theory. The table on this page shows the radiation unit for various materials in terms of gm/cm² and also in centimeters for standard densities.

From the radial curves of Fig. 2 the *total* energy loss within a plate can be obtained by numerical integration of the radial energy loss over the differential areas of the plate. When the total energy loss in a plate is plotted against depth, a so-called "transition" curve is obtained. Transition curves for the various elements investigated are shown in Figs. 4 and 5. By numerical integration over the intermediate circular zones, we can find the energy loss within any circular shell. Such data are given in the form of "block diagrams," Figs. 6–10. The figures in the blocks represent the energy loss, as a percentage of the total energy loss in the stack, in the individual (block) zones of revolution about the primary beam axis.

From the radial data or alternatively from Figs. 6–10, we can form the so-called "isoenergetic" curves of Fig. 11. The isoenergetic curves show at a glance how large a cylinder is required to capture *on the average* a given percentage of the total shower energy.

We have attempted to make an approximate energy balance similar to the one carried out previously (2). We have assumed that a range can be computed from the total energy (185 Mev) and the differential energy loss, dE/dx. Choosing such a computed range and the incident empirical value of dE/dx, measured at zero thickness on the transition curves of the various materials, we can calculate an area that is directly comparable with the area under the transition curve. It is to be pointed out that this type of check on energy balance is very sensitive to the shape of the incident beam. By using the value of dE/dx at the minimum of the collision loss curve for electrons we have obtained checks as follows: Carbon, theoretical area 0.5% high; aluminum, theoretical area 3% low; copper, theoretical area 30% low; tin, theoretical area 15% low; lead, theoretical area 1.8% low. Considering the numerous integrations required in making transition curves, the sensitivity to beam shape and the assumption made for dE/dx, the agreement is quite satisfactory in all cases, except in copper. It seems quite likely that the 30% discrepancy is due to beam shape effects at the beginning of the shower. This point merits further consideration.

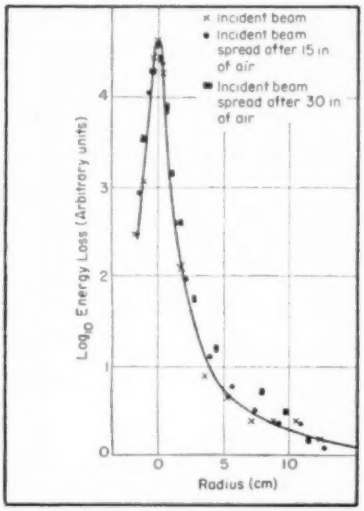


FIG. 3. Radial spread in air of incident beam

Estimates of Performance

The data of Figs. 2 and 4–11 offer a basis upon which to estimate the performance of large scintillation (or Cerenkov) counters in the neighborhood of 200 Mev. It may be noted in one of the preceding paragraphs that we have used the underlined expression "on the average." Since the data are taken by d-c techniques the luminescence observed in the probe scintillators is indeed the result of averaging over a large number of incident electrons. The interest in using a large crystal as a total-absorption spectrometer lies, however, in the crystal response to *individual* high-energy electrons, or gamma rays. It is possible to estimate the crystal performance for individual events by noting the fact that the radiation escaping from the greatest depths of the scintillation crystal must be of the maximum penetrability. For any given material this is gamma radiation lying at the minimum of the curve of absorption cross section versus energy of the gamma rays. For lead the minimum occurs at approximately 3.5 Mev. In this case, a sample of lead 14 radiation lengths long and 14 radiation lengths in *diameter* will capture on the average 90% of the energy of a single primary electron of energy 200 Mev (Fig. 11). An average of 10% of the energy escapes from the crystal in 5.7 parcels (gamma rays) of 3.5 Mev apiece. The statistics of the fluctuations in the number of escaping gamma rays can be approximated roughly by a Poisson distribution whose mean lies at 5.7 gamma rays.

Upon making such assumptions for lead and tin (absorption minimum of the latter at 4.0 Mev) the pulse-height frequency distributions (Figs. 12, 13) can be prepared. These curves indicate the type of pulse-height distributions to be expected if the fluctuations in the number of escaping gamma rays provide the principal cause of the width of the actual pulse-height distributions.

There will be an additional contribution to the width because of the statistical fluctuations in the number of photoelectrons appearing at the photocathode of the photomultiplier. If NaI(Tl) is used as a scintillator, a 200-Mev pulse will result in a light

Basic Data and Radiation Lengths for Five Elements*

Substance	Z	A	X_0 (gm/cm²)	E_0(Mev)	*Density* (gm/cm³)	l(cm)
Carbon	6	12	52	120	1.5†	34.7
Aluminum	13	27	26.3	52	2.70	9.8
Copper	29	63.6	13.3	22.4	8.94	1.49
Tin	50	118.7	8.9	12.5	7.28	1.22
Lead	82	207.2	5.9	7.8‡	11.34	0.522

* According to reference 6. In this table, X_0 is radiation length in gm/cm²; E_0 is critical density without density effect; l is the radiation length in cm for materials of standard densities.

† Commercial graphite was used in these experiments.

‡ Including correction to Born approximation.

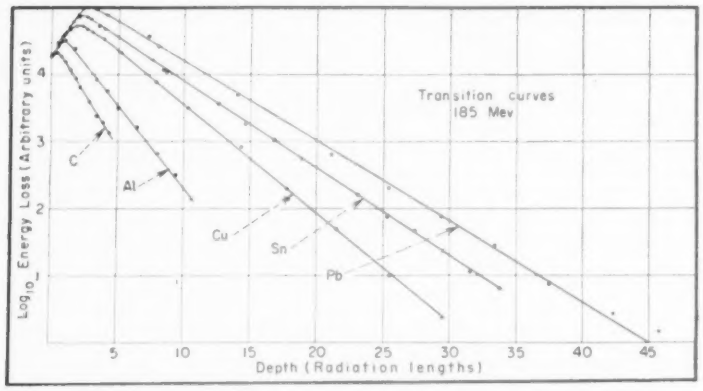


FIG. 4. Transition curves for five materials

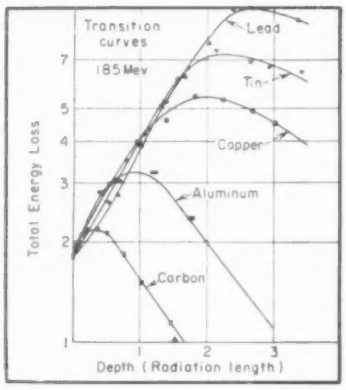


FIG. 5. Early parts of transition curves

flash corresponding to approximately 4×10^5 photoelectrons. The percentage statistical fluctuation of this number is microscopic in comparison with the straggling of the minimum-absorption gamma rays discussed above. However, if less efficient scintillators are used or if the optical collection is imperfect, such statistical fluctuations can be comparable with straggling and potentially serious.

In the case of Cerenkov counters only a weak light signal is to be expected. The statistical fluctuations of the photoelectrons can be serious and may become the dominating influence in determining the width of the pulse-height distribution. An estimate can be made as follows, first for Lucite (essentially carbon of density 1.18 gm/cm^3) and second for PbF_2 (essentially lead of density 8.24 gm/cm^3).

In Lucite one obtains about 15.7 photoelectrons per centimeter path length (*3*) of an energetic electron. A 200-Mev electron will have a "track length" (*1*) in carbon of approximately 1.67 radiation lengths or about 87 gm/cm^2, or about 74 cm of Lucite. Hence a total of approximately 1,040 electrons will appear in a single Cerenkov light flash if all the light can be collected and if an average of 90% of the primary energy is absorbed. The statistical spread of the photoelectrons will therefore be roughly $\pm 1/\sqrt{1{,}040} = \pm 3\%$. The escaping 10% of the original energy will lead to occasional large fluctuations since the absorption curve for carbon is essentially flat at energies higher than 10 Mev. In this case the limitations in the width of the pulse-height distribution will probably occur because of straggling and not because of an insufficiency of light.

To capture 90% of the original energy, the Lucite cylinder would have to be approximately 10 ft long and 1 ft in diameter. If a plastic scintillator is used instead of pure Lucite or polystyrene, the light yield will be more than sufficient, but because of the possibility of detecting proton recoils the counter will be sensitive to neutrons.

In PbF_2 the total electron track length will be about 26 radiation lengths or 19 cm, and thus about 295 electrons will appear at the photocathode for 90% absorption.* The statistical width of the pulse-height distribution is then made up of straggling ($\pm 4.5\%$) and photomultiplier statistics ($\pm 6.0\%$) to give an effective width of about $\pm 7.5\%$. At higher energies the effect of the photomultiplier statistics subsides. As a Cerenkov counter, PbF_2 may thus be moderately satisfactory provided that all the light can be collected. If this material could be activated so that it could scintillate, a most useful total-absorption spectrometer of small size could be developed.

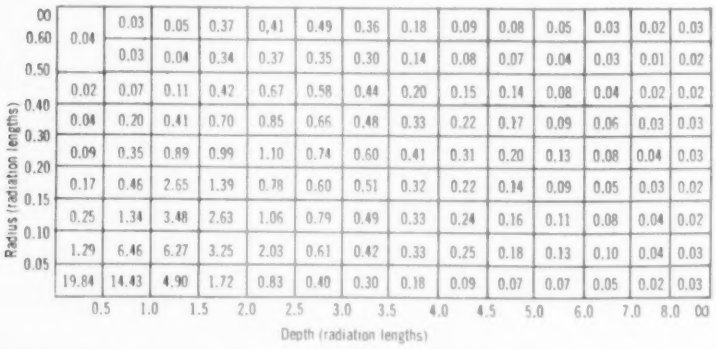


FIG. 6. Block diagram for carbon at 185 Mev. Scale compressed at high values

Similarity Rule

According to shower theory (*4*) (approximation *B*) the behavior of all materials is approximately the same when lengths are expressed in radiation units and when energies are expressed in units of "critical energy" = E_0. The critical energy is defined as the collision loss per radiation unit (of electrons of energy E_0). In practice this amounts approximately to the collision loss per radiation unit for electrons at minimum of the loss curve.

By applying this similarity rule we can convert the shower data herein reported to many useful scintillators or Cerenkov materials. For example, since the critical energy of iodine, about 12.5 Mev, ($A = 53$) is quite close to that for tin ($Z = 50$), we can use the shower data for tin as a good approximation when dealing with NaI(Tl). Similar substituting is possible for carbon and anthracene, and Lucite or organic liquid scintillators.

* The light flash is proportional to $\sin^2\theta$ where $\cos\theta = 1/n\beta$, where n is the index of refraction and β the ratio of the particle velocity in the medium to the velocity of light in vacuum. β is usually close to unity.

A rough approximation to the behavior of NaI(Tl) at 300 Mev can be obtained by using the data for Pb at 185 Mev by the similarity rule. Also carbon at 2.4 Bev corresponds roughly to Pb at 185 Mev. But this extrapolation must be treated cautiously.

Collection of Light

There are at least two approaches to the problem of light collection in the case of large scintillators:

1. Use of one large photomultiplier, or equivalently a large number of smaller photomultipliers.

2. Use of one small photomultiplier in a scheme similar to the "integrating sphere" method of photometry.

In the first method a "brute force" attempt is made to collect all the light from one large face of the scintillator. There would seem to be no objection in principle to this method provided that large photomultipliers are actually forthcoming. This seems quite likely since 7-in. diameter photomultipliers have already been produced. One advantage of this method is that low-energy gamma rays from radioactive sources such as Co^{60} (1.17, 1.33 Mev) can be used for calibration purposes.

In the second method a "peephole" in the large scintillator, to be surrounded preferably by an efficient diffuser and scatterer such as magnesium oxide, will be looked through by the small photomultiplier window. In this case a large loss of intensity will occur because of the numerous reflections that will take place before the light can emerge from the peephole. Perhaps a factor of 10 or 20 may be lost in this way. In such cases the use of radioactive calibrators will not be successful, but optical uniformity of the pulses should be quite high.

In the first case, it is also expected that the optical uniformity of the pulses will be satisfactory because the shower takes roughly the same path in the crystal for each event. In the case of nonuniformity of the surface of the photomultiplier, the method of Hudson and Roser (*5*) will be of help.

Linearity

In the case of relatively small counters for high energies, for example, a 10-in. long by 10-in. diameter NaI(Tl) crystal for energies of 500 Mev, it is not expected that the mean or most probable pulse height will be a linear function of the energy. On the other hand,

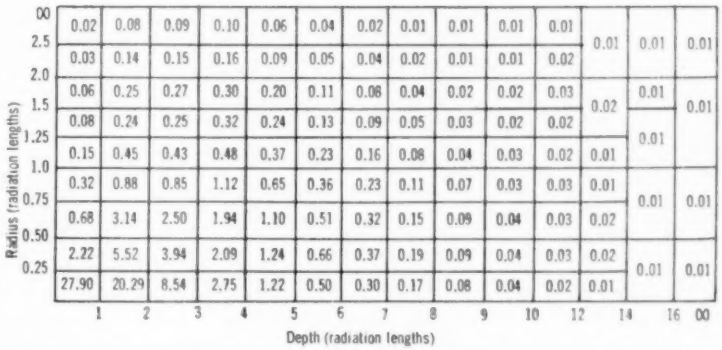


FIG. 7. Block diagram for aluminum at 185 Mev. Scale compressed at high values

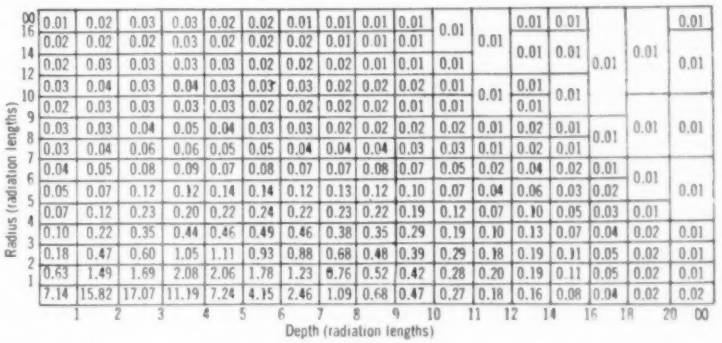


FIG. 8. Block diagram for copper at 185 Mev. Scale compressed at high values

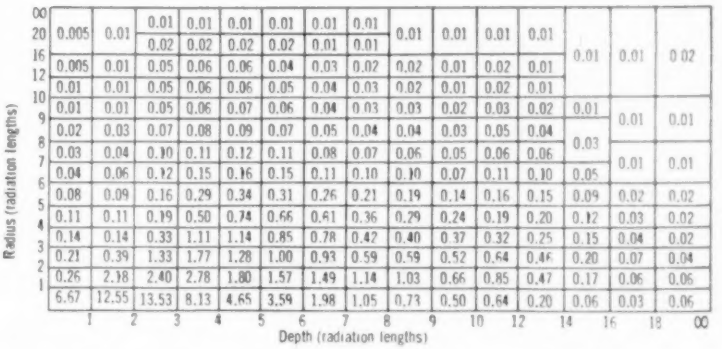


FIG. 9. Block diagram for tin at 185 Mev. Scale compressed at high values

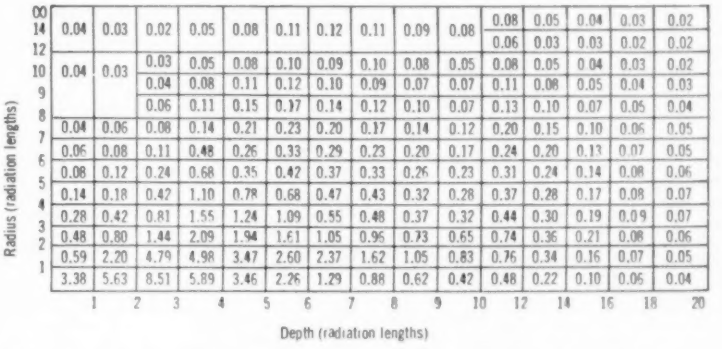
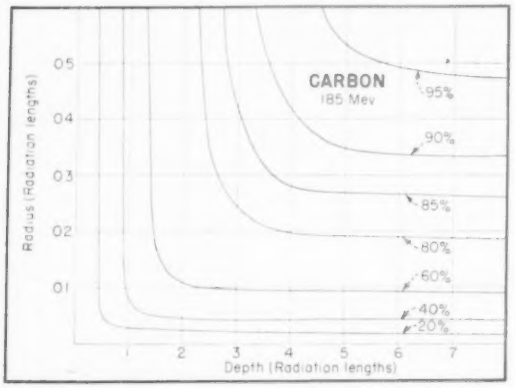


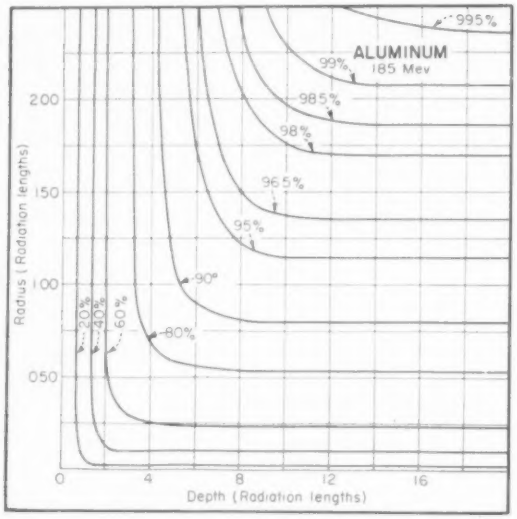
FIG. 10. Block diagram for lead at 185 Mev. Scale compressed at high values

at 200 Mev and below this energy the response of this counter will be closely linear. Where linearity is not observed, probably the best procedure will be to calibrate the large-volume counter with electrons of known energy. This is easily possible, for example, with the Stanford linear accelerator. Synchrotrons will also serve for suitable gamma-ray calibration.

Particles vs Quanta

Electrons (or positrons) and gamma rays are quite similar in regard to the electromagnetic showers produced by





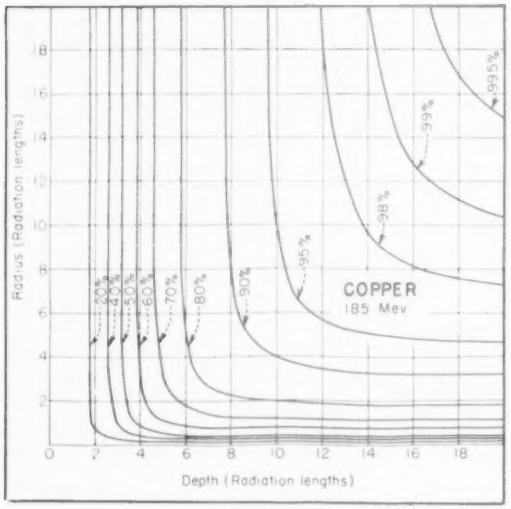
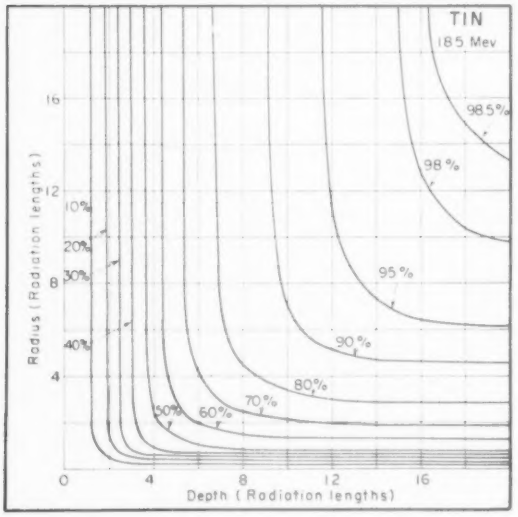
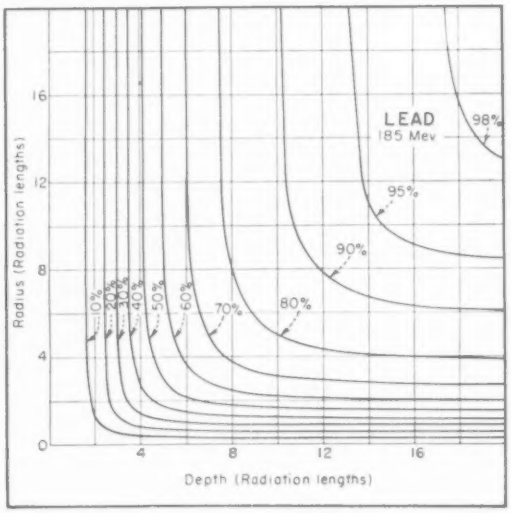


FIG. 11. Isoenergetic curves at 185 Mev for carbon, aluminum, copper, tin and lead





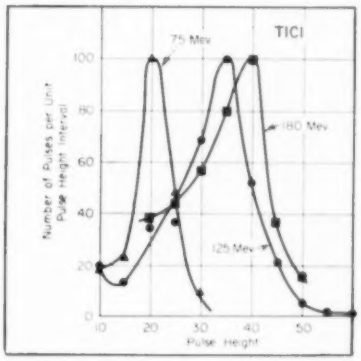
Experimental Confirmation

Preliminary results obtained with a thallium-chloride crystal used as a Cerenkov counter confirm the data presented in this article. The crystal was 3½ in. in diameter and 5 in. long, was tapered at one end due to the growing process, and had a density of 7.0 gm/cm³.

One would expect to obtain several hundred photoelectrons at the photocathode of the multiplier tube for each event occurring in the crystal at the energies considered here. The results actually obtained are shown in the figure at right. These preliminary measurements show some nonlinearity at the highest energy, probably from tube saturation.

Other possibilities for such a Cerenkov counter are dense glass, with a density of 5 or less, and lead fluoride, density as high as 8. Lucite or plastic phosphors would have to be 10 ft long and 14 in. in diameter for 90% capture of energy at 185 Mev.

(This work was carried out by J. H. Fregeau and R. Hofstadter.)



each species. But a gamma ray must penetrate on the average about one radiation length before it engages in the process of pair production and initiates a cascade. From there on the two cascade processes are identical. Hence about one radiation length should be added to the length of all large crystals when gamma rays are to be detected. Usually the number of radiation lengths is already so large that the addition of one more makes little difference in the length of the sample.

It is also quite possible to insert a thin (~2.0 mm) lead or uranium radiator in front of the large-volume scintillator so that the radiation process starts immediately and always from practically a fixed point. The loss of energy in the radiator is quite small.

Conclusions

It is expected with some confidence that the methods outlined here will eventually yield successful counters or high-energy particles and quanta. In fact it is highly probable that some material like PbF_2 or TlCl may be made to scintillate, even feebly. Because of the high energies available, the light pulses will still be very large, and it is expected that both shower straggling and photomultiplier statistics can be overcome.

Large-volume Cerenkov counters also seem to have definite possibilities, and a material like PbF_2 could, in principle, provide a spectrometer for energies as high as 10 Bev. Such a crystal would probably not have to be longer than about 80 cm and 30 to 50 cm in diameter.

No consideration has been given to particles, such as mesons or protons, that do not engage in shower production in a primary way. For these particles one also needs large counters, but in this case it is probably preferable to use stopping materials of medium atomic number since the collision loss is fairly high (1.6 Mev/gm/cm²) and densities can be obtained in the neighborhood of 5 or 6 gm/cm².

While total absorption spectrometers will be smaller than magnetic measuring devices, their weight and size will not be negligible. The crystal itself will weigh from 10 to 200 lb. More important, however, the shield will probably weigh a ton or so.

* * *

It is a pleasure to thank W. C. Sperry for considerable aid in taking data and for help in making various parts of our apparatus. The help of Phyllis Hanson and student operators of the linear accelerator is gratefully acknowledged. We wish to thank Victor Prosper for his assistance in constructing the frames supporting our shower piles, and for his general help in accelerating the construction of shower apparatus. This research was aided by the joint program of the Office of Naval Research and the Atomic Energy Commission.

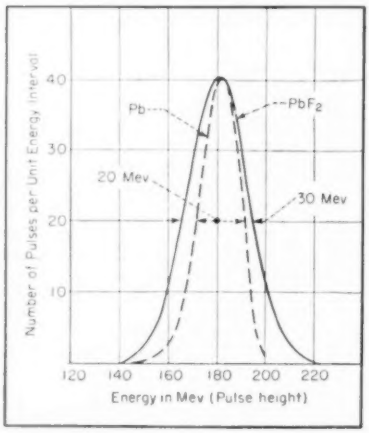


FIG. 12. Rough prediction of pulse-height distribution in lead-and PbF_2 at 185 Mev. In PbF_2 statistical fluctuations of photomultiplier photoelectrons cause added width. Width may even be greater because gamma rays of energy larger than 3.5 Mev may escape

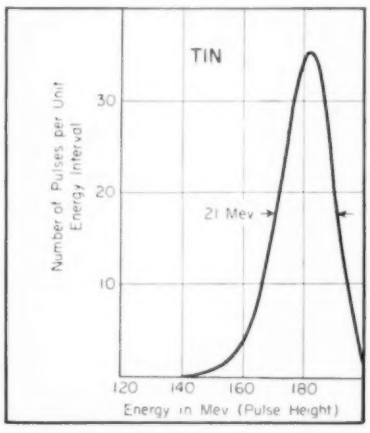


FIG. 13. Rough prediction of the pulse-height distribution in tin at 185 Mev. Tin is a good approximation to NaI(Tl). The width may be larger in the event that a significant number of gamma rays > 4.0 Mev escape from the sample

BIBLIOGRAPHY

1. B. Rossi, "High Energy Particles" (Prentice Hall, New York, 1952)
2. A. Kantz, R. Hofstadter, *Phys. Rev.* **89**, 607 (1953)
3. J. Marshall, *Phys. Rev.* **86**, 685 (1952)
4. Reference 1, p. 224
5. A. Hudson, F. X. Roser, *Bull. Am. Phys. Soc.* **28**, No. 7, paper B1 (1953)
6. B. Rossi, K. Greisen, *Revs. Mod. Phys.* **13**, 233 (1941)

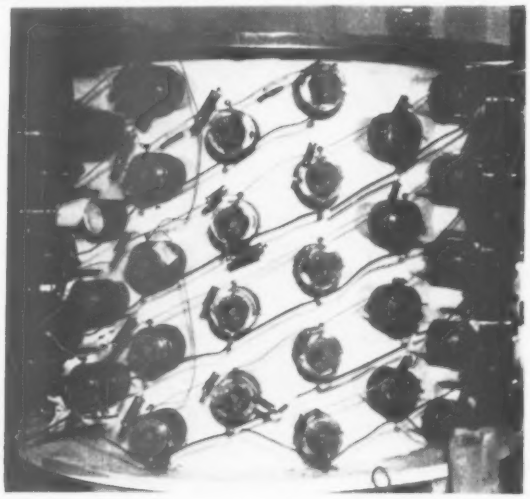


FIG. 1. Scintillation counter of 300 liters volume

Large-Volume Liquid Scintillators: Their Applications

- Efficient detection of neutrons, gamma rays, and lightly ionizing charged particles is provided by the 300-liter scintillation counter described here
- Applications include cosmic-ray measurements, neutrino detection, and determination of natural radioactivity in human beings
- Rate at which data is collected compensates for investment in photomultipliers

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LARGE VOLUME liquid scintillation counters have many desirable properties. Characteristic of detectors we have built (*1, 2*) are:

1. A large sensitive volume, with a mass of material in which an event may be detected that is orders of magnitude greater than that available in any other type of counter. In some experiments, particularly those involving cosmic rays, where the beam of particles is not collimated, this gives correspondingly greater counting rates.

2. A pulse-height resolution adequate for rough energy measurements, and for discriminating against unwanted events, has been achieved. But resolution is not comparable to that of a NaI scintillation spectrometer.

3. There is a possibility of time resolution in the region of 10^{-8} sec—depending on the pulse size—with volumes of a few hundred liters. The limiting factor is the time for collection of light from the scintillator.

4. Such a device has a high efficiency for detecting gamma rays. If the dimensions are larger than a few mean free paths, there is a good chance of collecting most of the energy by a series of Compton collisions, so that a measured spectrum will be simpler than with the ordinary scintillation spectrometer.

5. It is possible to incorporate in such a detector a neutron capturing medium such as cadmium, so as to detect neutrons by their capture gamma rays. The detection efficiency for neutrons of all energies is then high, and may be close to 100% for neutrons of a few Mev and below.

6. In a solution containing Cd, a fast neutron will give two pulses, the first being due to recoil protons, the second to the several gamma rays from capture in Cd. By requiring a delayed coincidence, it is possible to count fast neutrons with high efficiency in the presence of a background of charged particles, gamma rays or slow neutrons. Further, if the time of entry of the neutron into the system is known—as it would be in a cosmic-ray star, where the first pulse might be due to the entering particle or to charged particles or gamma rays from the star—the neu-

trons need not be fast to give delayed pulses.

Neutrino Counter

A scintillation counter, developed at Los Alamos for the detection of the neutrino, has many applications to other measurements, for example in the field of cosmic rays. We have at present two detectors, of 300 liters volume, in the shape of a circular cylinder 75 cm in diameter and 75 cm high (Fig. 1). One of the counters is of mild steel, the other of stainless. Stainless steel is probably to be preferred as a construction material because it eliminates the possibility of contamination by rust. The inside coating of the tank is painted white; this was found to work better than a specular reflector such as aluminum foil. Either a commercial porcelain, or a paint made up of TiO_2 and water glass has been found to give a satisfactory surface.

The detector has 90 photomultipliers, either 5819's or 6292's, arranged around the periphery in a reasonably isotropic array. The tubes are connected in spirals, and alternate spirals are connected together to form two banks. These two banks are run in coincidence to reduce the effects of tube noise and afterpulsing.

Originally we used each photomultiplier with a high-voltage capacitor at the output, but these gave trouble by frequent breakdowns. With the present arrangement, the cathodes are grounded, the anodes are tied in parallel, and the tubes are balanced for equal gain by means of a resistor that puts the surplus voltage between the last dynode and anode, where it does not affect the gain.

A thin copper sheet is put around the outside, supported by the two flanges, to serve as an electrostatic shield and to protect personnel against the high voltage.

We have been primarily interested in the detection of the neutrino, which presumably interacts with a proton in the scintillator, producing a positron of a few Mev and a neutron of a few kilovolts energy. The positron is detected promptly, the neutron a few microseconds later by virtue of the cadmium capture gamma rays. We therefore look for delayed coincidences, with a time delay and second pulse size similar to those produced by a fast neutron.

The pulses from the two banks go through nonoverload amplifiers to a delayed coincidence set that has two sets of gates, one labeled "first pulse" and one "second pulse" (see Fig. 2). If pulses appear simultaneously from both banks, each in the right pulse-height range, they will trigger the "first pulse" circuit, and similarly the "second pulse" circuit. Pulses from these two circuits are fed to the time delay analyzer, which gives a count any time a "first pulse" is followed within the range 1-10 μsec by a "second pulse," indicating into which one of 18 channels ½-μsec wide the time delay between the pulses fell. The two sets of pulses are also used to gate a 10-channel pulse-height analyzer that can be set to measure either the first or the second of a pair of pulses.

Fillings

We have used two fillings, one of toluene-terphenyl-α-naphthyl phenyl oxazole (αNPO), and one with the same ingredients plus methanol and Cd propionate. The propionate was the only Cd compound found that was soluble in the scintillator, did not quench the fluorescence or absorb the light too drastically, and did not affect the other compounds. The actual mixture used contained 7½% Cd propionate, and 14% methanol, which was necessary to get the propionate into solution. For this solution the ratio of the number of Cd atoms to H atoms was about 0.003.

It is important to use anhydrous Cd propionate, and to remove as much water as possible from the solvents before mixing; otherwise a hydrate is formed that separates out as a second liquid phase.

We felt that Cd was preferable to B in a large scintillator, whereas B is probably better in a small volume (3). Because of the nonlinearity of the scintillator response to heavily ionizing particles, the α-particle from the $B^{10}(n,\alpha)$ reaction only gives light equivalent to that produced by a 120-kev electron. This means that even when the 480-kev gamma ray is captured, the total pulse is equivalent to 600 kev, at which level the background in our counter can be severe. Capture in Cd, on the other hand, produces a total of 9 Mev, usually divided between three to five gamma rays. These gamma rays would be likely to escape from a small scintillator, but are detected in ours with high efficiency, enabling us to

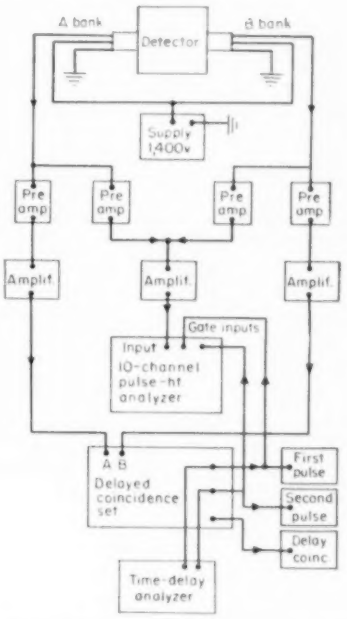

FIG. 2. Electronics for detection of particles producing delayed coincidences

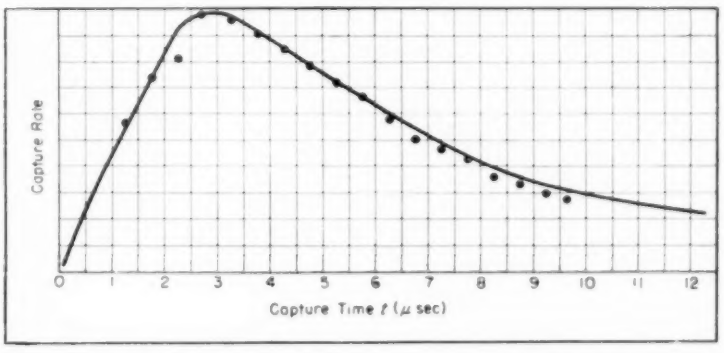

FIG. 3. Time-delay spectrum for neutron captures in liquid scintillator containing cadmium

set the lower gate at 2 or 3 Mev, thus reducing the background counting rate by more than an order of magnitude from what it would have been had boron been used as the neutron capturer.

Light Collection

The efficiency of light collection depends on three factors: the cathode area, the reflectivity of the walls, and the absorption of light by the scintillator.

In the detector under discussion, the fraction of wall area covered by cathodes is 4.5%. In future detectors, it would probably be advantageous to use tubes with larger cathodes, such as the 5-in. K1198 that has seven times the cathode area of the 2-in. tubes.

We have not as yet measured the reflectivity of the walls of our detector, and in particular do not know the effect on the reflectivity of having the surface immersed in liquid rather than air. For purposes of calculation the reflection coefficient was taken to be 90%.

The scintillation light is emitted in a band centering on 4,200 Å, due to the wavelength shifter (αNPO). At this wavelength the mean free path in the Cd solution is about 1 meter, and the mean free path in the other solution is greater than 5 meters.

From these figures we estimate that the fraction of light arriving at the photocathodes is 8% and 18% respectively for the solutions with and without Cd. The ratio of these numbers is confirmed experimentally: the Cd solution is half as efficient a scintillator as the other in small volumes, and the pulse heights from the Cd solution in the tank are $\frac{1}{4}$ as great as from the solution without Cd.

Using these figures for light collection, we conclude that 100 electrons are ejected from the photocathode per Mev of energy loss in the scintillator without Cd, and 25 photoelectrons per Mev with Cd. This figure holds only for lightly ionizing particles.

For the solution without Cd, the light makes many traversals of the tank, and the same fraction is lost in each, so that a sharp pulse of light will appear to decay exponentially with a mean life of 2×10^{-8} sec, about ten times as long as the decay time of fluorescence in terphenyl-toluene. This sets a limit on the time resolution.

Neutron Time Delay

Figure 3 shows a typical time-delay spectrum from neutron captures. The line gives the calculated time distribution between the arrival of a fast neutron and its capture (*2*); the points are measured values for neutrons produced by the cosmic radiation. The time distribution is very insensitive to the energy of the incident neutron down to a kilovolt or less. This curve is to be compared to the exponential decay expected with boron due to its $1/v$ neutron capture cross section. The Cd time response is more easily differentiated from a normal decay curve, and if as in our case it is inconvenient to use the first microsecond following the entry of the neutron into the system, a smaller fraction of the counts is lost.

Calibration

For energy calibration, we have used gamma-ray sources, such as Co^{60}; the peak given by mesons passing all the way through the tank; and the end-point of the μ-meson decay electron spectrum.

Figure 4 shows the measured spectrum of gamma rays from Co^{60}, using the solution with no Cd. The two gamma rays of 1.17 and 1.33 Mev are not resolved. The two peaks correspond to the partial degradation of one or both gammas. The upper end of the curve is at 2.5 Mev.

Figure 5 shows the pulse-height distribution due to cosmic radiation. The peak is due to single relativistic particles passing through the tank. Because of the angular distribution of incident mesons, the maximum corresponds to 1.03 times the vertical distance through the tank, or about 115 Mev. The energy scale on this figure is derived from the third method of calibration; agreement is within the limits of error of the calculations.

μ-Meson Experiments

The pulse-height calibration and the time-delay analyzer calibration, using μ-meson decays, merit a more detailed description because they illustrate the potentialities of this detector for cos-

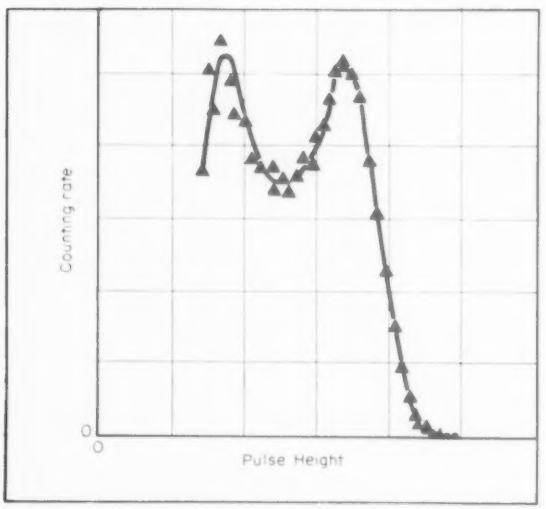

FIG. 4. Pulse-height spectrum from Co^{60} source in center of large liquid scintillation counter

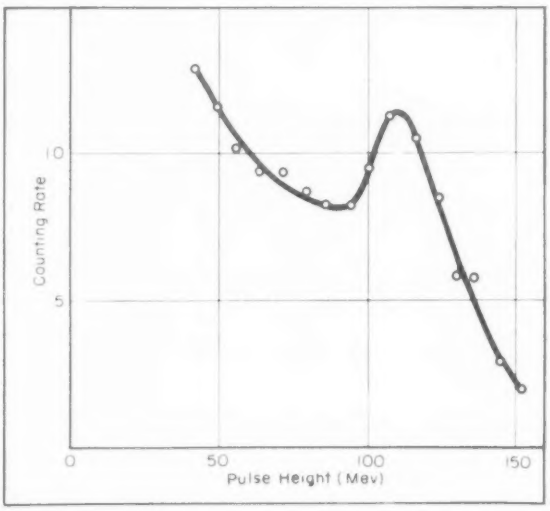

FIG. 5. Pulse-height spectrum due to cosmic rays passing through large liquid scintillation counter

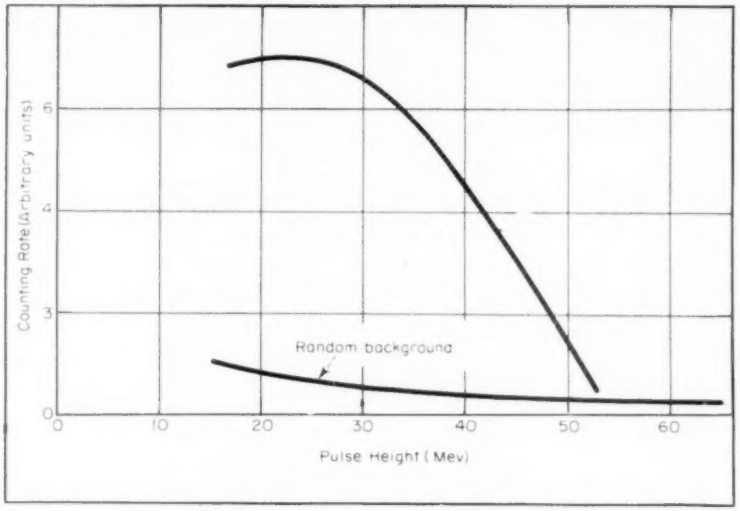

FIG. 6. Pulse-height spectrum of decay electrons from μ-mesons. Background indicated has not been subtracted from data plotted

mic-ray research. Assuming that the μ-meson decays into an electron and two neutrinos, the end-point energy of the electron is 53 Mev. The maximum range of an electron of this energy in the scintillator is 35 cm, so that there is a good chance that a decay electron will remain in the tank over its whole path.

Figure 6 shows the measured pulse-height spectrum of second pulses, when the first pulse is required to be greater than 10 Mev. The lower line shows the background due to chance coincidences. The data were taken in three runs totaling 12 hours running time, and represent about 40,000 counts.

To find the true energy spectrum, it is necessary to correct the measured spectrum for leakage of electrons through the walls, and for bremsstrahlung losses. The correction for the resolution of the counter, which should give less than 2 Mev half-width at 50 Mev, is unimportant. These corrections change the shape of the spectrum, but do not appreciably move the end-point.

As a check on the functioning of the time-delay analyzer, we measured the decay time of the μ-meson. Figure 7 shows the results of a measurement taken at the same time as the data for Fig. 6. An analysis of the data gives a mean life of 2.10 ± 0.02 μsec, to be compared with the value 2.12 ± 0.02 obtained by Bell and Hincks (*4*) for the natural mixture of μ-mesons in carbon. This is not to be taken as a new measurement of the μ-meson mean life, since that would require an independent calibration of the measuring system.

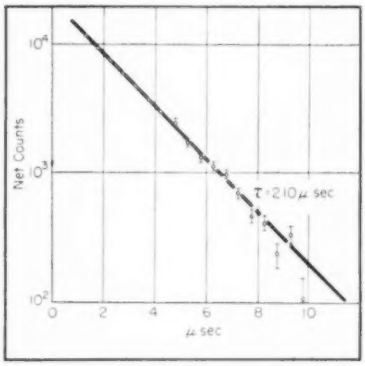

FIG. 7. Time-delay spectrum of μ-meson decays

Body Radioactivity

The high sensitivity of the detector to gamma rays has been used to measure the natural radioactivity of human beings (*5*). Most of the activity can be ascribed to K^{40}, occurring to the extent of about 10^{-8} curies in the average person. The determinations can be made in a few minutes and offer a method of measuring levels of activity well below tolerance.

Conclusions

In a detector such as ours, the most expensive item is the photomultipliers, which cost about $5,000. If it is possible to tolerate the relatively large transit-time spread in the large-cathode tubes such as the K1198, the cost goes down from about $4.00 to about $1.50 per cm^2 of cathode area, so that substantial savings should be possible.

As anyone who has painstakingly collected data at the rate of a count or so per hour knows, one of the most important factors in determining the feasibility of a cosmic-ray experiment is the expected counting rate. We feel that many cases exist in which the gain in counting rate from the use of a large scintillator will be great enough to make its construction worthwhile.

Another important feature of such a scintillator is its high efficiency for the detection of neutrons of all energies, and particularly in the range of a few Mev, where other types of counters are relatively inefficient. There are interesting possibilities, for instance, in the measurement of neutrons associated with various types of cosmic-ray events.

* * *

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BIBLIOGRAPHY

1. C. L. Cowan, Jr., F. Reines, F. B. Harrison, E. C. Anderson, F. N. Hayes, *Phys. Rev.* **90,** 493 (1953)
2. F. Reines, C. L. Cowan, Jr., F. B. Harrison, D. Carter, to be submitted to *Rev. Sci. Instr.*
3. C. O. Muehause, G. E. Thomas, Jr., NUCLEONICS **11,** No. 1, 44 (1953); R. Cleland, *Bull. Am. Phys. Soc.* **27,** 5 (1952); J. Kirkbridge, *Nature* **171,** 564 (1953)
4. W. E. Bell, E. P. Hincks, *Phys. Rev.* **88,** 1424 (1952)
5. F. Reines, R. S. Schuch, C. L. Cowan, F. B. Harrison, E. C. Anderson, F. N. Hayes, *Nature* **172,** 521 (1953)

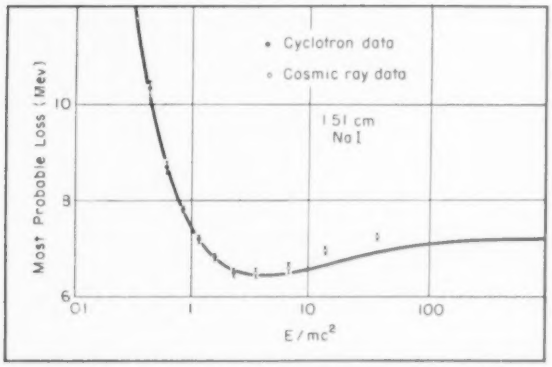
Next month . . .

a comprehensive Special Report on

Research Reactors

including discussion of all aspects of this growing field: use and experimental requirements, current designs, materials, location and security problems. Present status of plans for research reactors in the United States will be reviewed.

High Energy and Cosmic Rays



COMPARISON of results for NaI scintillators to curve calculated by Sternheimer (Bowen)

Detection and energy classification of charged particles from photonuclear reactions, by D. J. Zaffarano, Iowa State College, Ames, Iowa. The energy spectrum up to 10 Mev of protons, deuterons, or alpha particles can be measured in the presence of other charged particles by means of a wafer-type multiple-wire proportional counter and an adjacent scintillation crystal spectrometer contained in the same gas chamber. Coincident pulses, proportional to dE/dx (proportional counter) and E (scintillator), from the traversal of each particle are displayed in quadrature on an oscilloscope. The face of the cathode-ray tube is masked to expose only the hyperbolic range-energy locus desired, and is photographed with a moving-film 35-mm camera.

The film is scanned automatically after development to yield 100-channel energy spectra with good statistics. No difficulty was encountered in alpha-particle identification, but separation of proton and deuteron loci was hindered because of statistical fluctuations in energy loss. But by discriminating against particles whose energy loss deviates appreciably from a most probable value, detection of a particular particle type is possible.

Investigation of techniques in coincidence counting with millimicrosecond resolution, by George A. Minton, National Bureau of Standards, Washington, D. C. With a differential coincidence circuit similar to that described by S. De Benedetti and H. Richings [*Rev. Sci. Instr.* **23,** 37 (1952)], the best resolution obtained was 0.7 mμsec full width at half-maximum with radiation from Co^{60}. In this circuit, pulses are shaped so that their width is proportional to the rise time from the photomultiplier.

The response of NaI scintillators to high-energy mesons, by T. Bowen, Dept. of Physics, University of Chicago, Chicago, Ill. Energy loss in a scintillator as a function of energy of the incident particle has been determined for NaI crystals. Mesons produced by the Chicago synchrocyclotron have been used to cover energies from 66–250 Mev; cosmic μ-mesons, for 310 Mev to > 2 Bev.

For measurements below 250 Mev, three small NaI crystals were used, one to measure pulse height, the other two to trigger the electronic circuits. Absorbers between the latter were used to select μ-mesons. The apparatus gave a resolution of 16% at half-maximum for the Cs line.

Similar crystals were used in a cosmic-ray telescope above 310 Mev.

Results were in good agreement with the most probable energy loss predicted by the Bethe-Bloch formula for NaI with the nonrelativistic cyclotron-produced mesons. As shown by the figure, mesons of relativistic energies gave results in fair agreement with the calculations of Sternheimer [*Phys. Rev.* **88,** 851 (1952); **91,** 256 (1953)]. A relativistic increase in probable loss is indicated above 310 Mev.

Capture of μ-mesons in a liquid counter, by T. N. K. Godfrey, Princeton University, Princeton, N. J. An organic liquid scintillation counter has been used in a study of the nuclear capture of negative μ-mesons in carbon [*Phys. Rev.* **92,** 512 (1953)]. This counter uses two RCA type C7157 photomultipliers in conjunction with a short light pipe to view a rectangular tank containing 3 gm/l of terphenyl and 10 mg/l of diphenylhexatriene dissolved in phenylcyclohexane. The $4 \times 4\frac{3}{4} \times 5$ in. tank is made of $\frac{1}{8}$-in. Lucite sheets cemented with acetic acid. The outside of the tank is painted white.

This counter is placed in a cosmic-ray telescope that selects events to be measured. Pulses produced directly by the μ-meson have a mean life of 2 μsec; those produced by capture and emission of a B^{12} beta particle have a mean life of 32 msec. Discrimination between these events is accomplished by displaying the counter pulses on an oscilloscope. A 100-msec sweep circuit is triggered by pulses produced in the telescope G-M counters; the displacement of a scintillation pulse is then a measure of decay time.

Use of a nonlinear circuit element between the pulse amplifier and oscilloscope improved performance. Full width at half maximum of the pulse-height distribution from the scintillation counter is about 35% of the most probable pulse height.

Total-Absorption X-ray Spectrometry

Application to Betatron Experiments

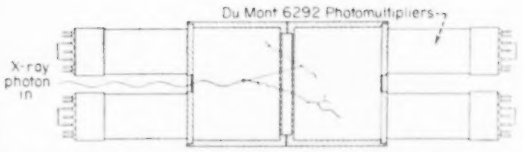


FIG. 1. Sectional schematic of the total absorption X-ray spectrometer. Typical cascade interactions resulting from the absorption of one X-ray photon are pictured

Detection efficiency larger than 80%, combined with energy resolution better than 11% from ½ to 50 Mev, make this NaI(Tl) spectrometer ideal for betatron experiments. The unit is described, and NBS research outlined

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A SODIUM IODIDE scintillation spectrometer has been built that can measure the energy of individual X-ray photons in the range from ½ to 50 Mev with an energy resolution better than 11% and a detection efficiency larger than 80% (*1*). The spectrometer is called a total absorption spectrometer because individual X-ray photons that enter the device are almost totally absorbed in a scintillator. The absorption results in a light pulse. The magnitude of a majority of the light pulses is proportional to the X-ray photon energy.

Physical Characteristics

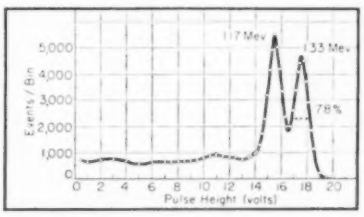
Figure 1 shows a schematic diagram of the sodium iodide crystals and light detectors. The 8-in. long by 5-in. diameter scintillator is composed of two 4-in. long crystals. Four DuMont 6292 photomultipliers detect the light from each crystal. Voltage pulses from all eight photomultipliers are added to obtain a single voltage pulse proportional to the total electronic energy expended in the two crystals.

Figure 2 shows a photograph of the spectrometer with the relevant components labelled. An access hole through the electronic chassis, photomultiplier array, and glass of the crystal containers permits a ¾-in. beam of X-rays to be admitted to the crystals without appreciable interaction with intervening materials.

Figure 3 shows the details of the crystal containers and potting procedures used in our laboratory. Further details are reported elsewhere (*1*).

Operating Characteristics

When used for measuring X-ray spectra, the spectrometer is completely surrounded by a 4-in. lead shielding wall. A ½-in. diameter hole in this wall is used to admit an X-ray beam



PERFORMANCE of total-absorption spectrometer is indicated by pulse-height distribution produced by Co^{60} gamma rays when 5-in. crystal 4 in. long is used

along the axis of the spectrometer crystals. With approximately this arrangement for all photon sources, voltage pulse-height spectra were measured for monoenergetic gamma rays by individual detection of photons, using single-channel and multi-channel differential analyzers (*1*). A typical example of the spectrum obtainable with the two gamma rays from cobalt is shown at the left.

If one defines the energy resolution of these pulse-height distributions as the width at half of the maximum intensity divided by the pulse height at this maximum, then one can summarize the pertinent results with a plot of energy resolution versus gamma-ray energy (Fig. 4). The corrected experimental data (open-circled points), together with theoretical data (*1*) show that the resolution has a minimum value of 6% at about 3 Mev and is less than 9% from 3 Mev to 40 Mev.

General Applications

Numerous applications of total absorption spectrometers to nuclear physics research should arise because these spectrometers have:

1. A detection efficiency of almost 100%. The high detection efficiency of total absorption spectrometers is in

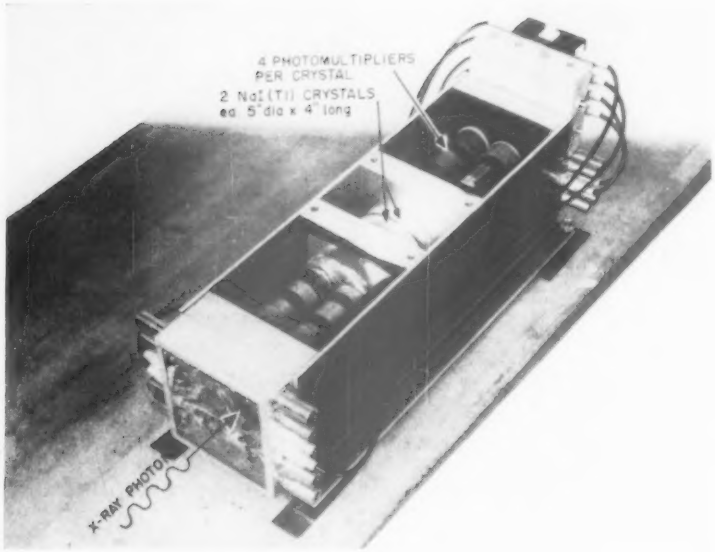


FIG. 2. Assembled spectrometer

strong contrast to other spectrometers, such as pair or Compton magnetic spectrometers (*2*) that have detection efficiencies of the order of 10^{-3}%. This feature is very important for most experiments and makes possible the use of good geometries and weak sources.

The constancy of the detection efficiency at close to 100% for different photon energies was important in a recent experiment (*3*) with the gamma rays from Ba^{133}. A determination of the ratio of the number of 82-kev to 360-kev gamma rays with a large crystal spectrometer made it possible to evaluate accurately the conversion efficiency for the 82-kev level.

2. A pulse-height distribution for monoenergetic X-ray photons that has one predominant peak and little "tail" at small pulse heights. This characteristic is in striking contrast to a small crystal spectrometer (*4*). It will be important for the interpretation of thin- and thick-target bremsstrahlung spectra in the range from 100 kev to several Mev. The research is now in progress with a total absorption spectrometer by J. Motz, W. Miller, and H. O. Wyckoff (*5*).

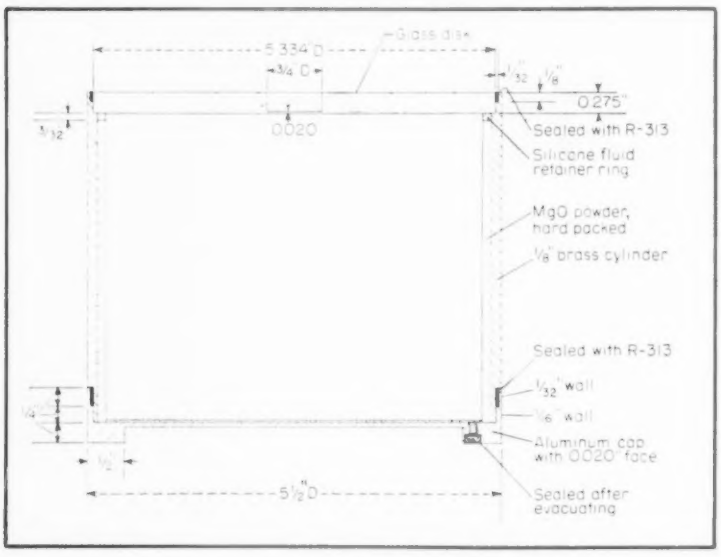


FIG. 3. NaI(Tl) crystal container. All crystal surfaces are sanded

3. A wide energy range coverage in one instrument. The possibility of examining spectra from 100 kev to 50 Mev is proving very valuable for experiments now in progress with a 50-Mev betatron. No other instrument available can be used over this wide a range. For example, pair spectrometers cannot be used below 1 Mev, while Compton line spectrometers become unusable above 5 Mev because of their intolerably low detection efficiencies.

Betatron Experiments

Made practical with total-absorption spectrometers, the following research is in progress at the National Bureau of Standards:

1. Determination of the shape of the X-ray photon spectrum from a betatron. The technical problems in this research arise because all X-ray photon energies up to a given maximum energy are present in the X-ray beam and because the X-rays are emitted in bursts. As a result, in the application of a conventional spectrometer such as a pair spectrometer to the measurement of 20-Mev betatron spectra, experimental times longer than a week are required because of the small "on-time" of the betatron X-rays (*6*). On the other hand, a total absorption spectrometer of the same time and energy resolution can obtain comparable data in times of the order of hours. The decrease in the required time results from the higher detection efficiency of these spectrometers and from the elimination of the need for a coincidence of two events as in a pair spectrometer.

2. The study of the "giant resonance" nuclear absorption. It has been found experimentally (*7*) that X-ray absorption by the nucleus that results in proton and neutron emission exhibits a giant resonance cross section for high-atomic-number materials that extends over several Mev with a relatively large cross section. The effect of nuclear absorption of X-rays can be demonstrated directly (*1, 8*) by examining the "white light" spectrum of betatron X-rays after it has been transmitted by long absorbers in a good-geometry experiment. Any predominant absorption of photons over a limited energy range will result in absorption dips or bands analogous to the absorption bands in atomic absorption spectroscopy. A total absorption

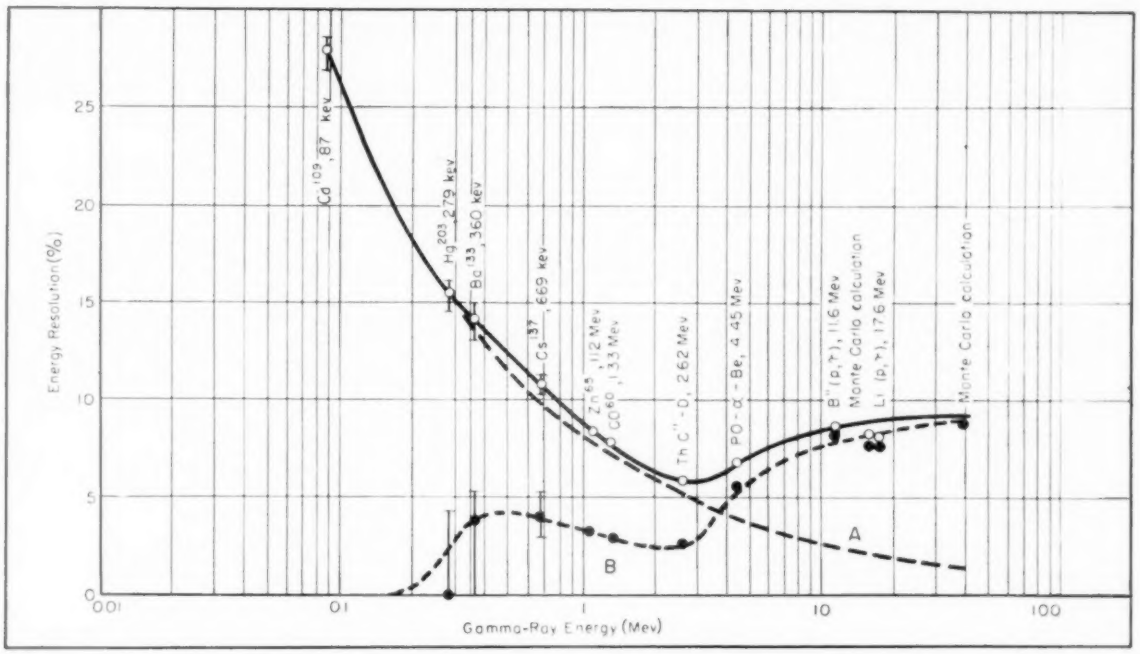


FIG. 4. Per cent energy resolution (solid curve) as a function of the gamma-ray energy. Resolution was analyzed into per cent contribution due to statistical fluctuations (curve A) and per cent contribution due to energy loss from crystal (curve B)

spectrometer, which determines the number of X-ray photons at each energy in the transmitted spectrum, makes the necessary experimental conditions possible because of its high detection efficiency.

The dip in the pulse-height distribution obtained with a total absorption spectrometer, Fig. 5, demonstrates the nuclear absorption in copper. It was produced by 30-Mev betatron X-rays that were transmitted by 30 cm of copper. The dip at 42 divisions is approximately a 33% drop in intensity and occurs at 18.1 Mev. Although the magnitude of nuclear absorption relative to other absorption processes decreases with increasing atomic number, the dip for uranium for the conditions of the copper experiment would be about 16% in magnitude and, thus, should still be easily observable.

3. Observation of X-ray absorption by individual nuclear levels. A dip in the transmitted X-ray spectrum will also be observed for absorption by certain individual nuclear levels in low-atomic-number nuclei. It is difficult to predict the levels that should be observable because the particle and radiation width data for nuclear levels is very fragmentary. For example, Ajzenberg and Lauritsen (*10*) give data useful for the experiments now underway at the National Bureau of Standards for only three energy levels in two nuclides. It can be shown that for these levels, dips of the order of 1 or 2% and ½ Mev wide should be observable under the conditions of a long-absorber, good-geometry experiment.

In our preliminary experiments, 2% dips and larger are being observed in statistically significant pulse-height distributions containing 200,000 counts. These experiments require 2 to 4 hour running times and, thus, are practical.

The technique of observing dips in a transmitted X-ray spectrum that are produced by individual nuclear level absorption should prove to be a useful tool for nuclear research. Those nuclear levels that absorb sufficiently will all appear in one absorption spectrum.

Absolute energy spacings and radiation transition probabilities for many levels should be obtainable from a careful and detailed examination.

* * *

This work has been assisted by the Office of Scientific Research of the Air Research and Development Command. The paper on which this article is based was presented at the Scintillation Counter Symposium, Washington, D. C., January 26, 1954.

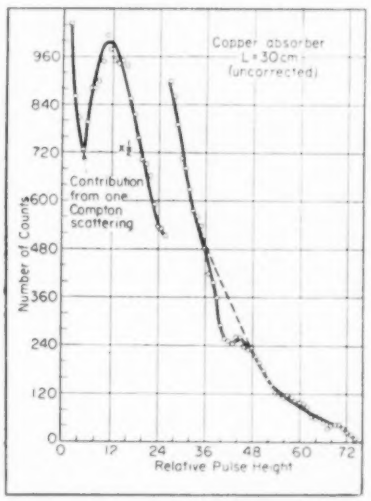


FIG. 5. Pulse-height distribution produced by 30-Mev betatron X-rays transmitted by 30 cm of copper

BIBLIOGRAPHY

1. R. S. Foote and H. W. Koch, *Rev. Sci. Instr.* **25** (in press)
2. J. Motz, W. Miller, H. O. Wyckoff, *Rev. Sci. Instr.* **24,** 929 (1953)
3. R. W. Hayward, D. D. Hoppes, H. Ernst, *Bull. Am. Phys. Soc.* **28,** 12 (1953)
4. R. Hofstadter, J. A. McIntyre, NUCLEONICS **6,** No. 3, 32 (1950)
5. J. Motz, W. Miller, H. O. Wyckoff, private communication
6. J. L. Lawson *et al.*, Quarterly Progress Report No. 6 (General Electric Research Laboratory, Contract N7onr-332, 1948)
7. G. C. Baldwin, G. S. Klaiber, *Phys. Rev.* **73,** 1156 (1948)
8. A. G. W. Cameron, *Phys. Rev.* **82,** 272 (1951); R. Nathans, J. Halpern, *Phys. Rev.* **92,** 207 (1953)
9. F. Ajzenberg, T. Lauritsen, *Revs. Mod. Phys.* **24,** 321 (1952)

Spectrometry

The total absorption spectrometer, by P. R. Bell, Oak Ridge National Laboratory. Large sodium iodide crystals assist in elucidation of decay schemes. The detector shown in Fig. 1 approximates a 5¼-in. sphere, and has an alpha-alumina reflector. The response to a chromium-51 source is compared in Fig. 2 to the response of a 1½-in. diameter × 1-in. crystal. The photoelectric peak at 320 kev is followed by a Compton spectrum. The Compton contribution has been largely eliminated by use of the well-type large crystal. It should be noted that the small bump in the well curve was found to be due to Compton electrons from the aluminum source holder. The curve shown by the dotted lines has the holder removed.

Cobalt-60, which emits two simultaneous gamma rays, 1.17 and 1.33 Mev, is shown in Fig. 3. The lower curve is for the source external to the crystal and shows the two gamma ray peaks followed by some Compton contribution. Since both gamma rays are emitted simultaneously in different directions from the nucleus, only one will be detected by the crystal at any time; thus each energy is detected separately.

When the source has been placed in the well, both the simultaneous gamma rays are absorbed giving a peak that is total energy of 2.5 Mev. Since this particular crystal size is not large enough to absorb totally all the gamma-ray energy, there is also some response where one or the other gamma ray is totally absorbed, where one is totally absorbed and part of the energy from the other is absorbed with some escaping, plus the case where only part of the energy from both gamma rays has been detected. In a larger crystal, perhaps as much as 10 in. in dia. and 10 in. high, there would be total absorption and only the total energy peak at 2.5 Mev would appear.

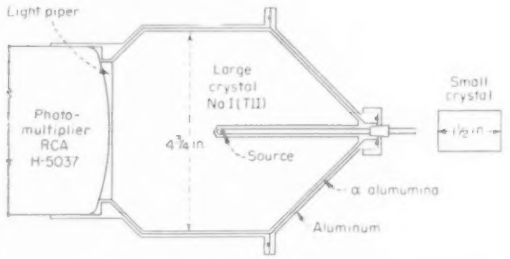


FIG. 1. Detector for total-absorption spectrometer, with small crystal shown for comparison (Bell)

A 3-in. diameter × 3-in. high NaI(Tl) crystal was used with a Du Mont K-1197 photomultiplier tube. The source is external to the detector. The best resolution of the cesium-137 line that has been obtained with this detector has a full width at half-maximum of 7½%. When a source is placed at short distance (3 cm) from the NaI crystal, the upper curve in Fig. 4 is obtained. When the source is at a greater distance, in this case 9.3 cm, the shape of the Compton response has been changed. It has a definite slope of pulse-height distribution, and there is considerable rounding of the shape at the low-energy end. The difference is due to the small absorption present at the corners of the crystals. Removal of these top corners

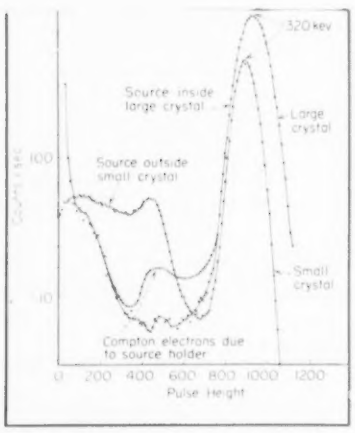


FIG. 2. Large crystal vs small crystal results for chromium-51 (Bell)

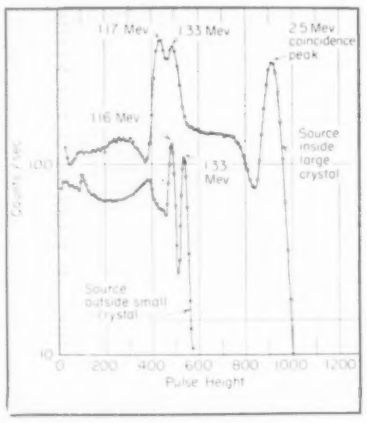


FIG. 3. Results with cobalt-60 for large and small crystals (Bell)

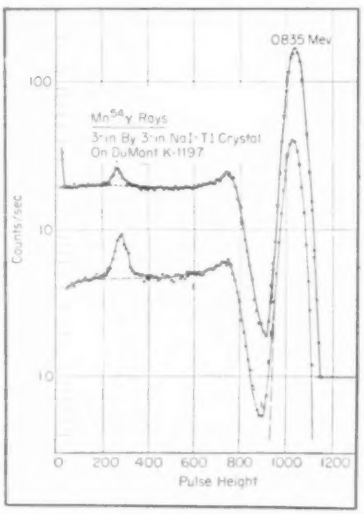


FIG. 4. (right) Effect of source-detector distance (Bell)

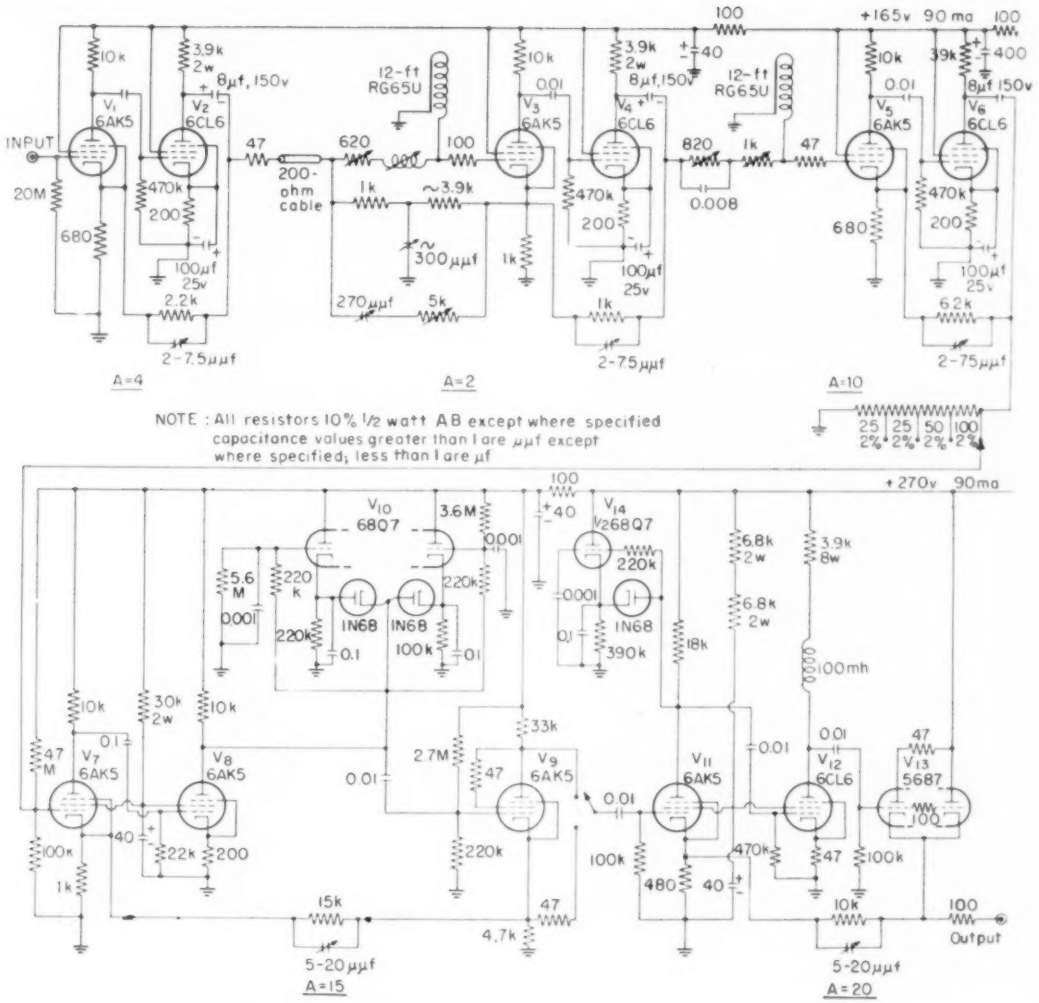


FIG. 5. Circuit of double-line linear amplifier (Francis, Bell, and Kelley)

does not change the resolution of the photoelectric peaks. However there is a reduction in the effect as noted previously. The Compton pulse-height distribution is noticeably reduced.

Double-line linear amplifier, by J. E. Francis, P. R. Bell, and G. G. Kelley, Oak Ridge National Laboratory, Oak Ridge, Tenn. One of the stringent requirements when using scintillation spectrometers deals with the measurement of small pulses in the presence of large pulses. The double-line linear amplifier has good operating characteristics under overload conditions, and a high degree of linearity and stability.

The unit is shown in Fig. 5. The preamplifier is located at the photomultiplier tube. The signal is coupled into the amplifier through a 200-ohm line. Double differentiation, by means of shorted delay lines, shapes the pulse so that there are equal excursions on both sides of the base line, separated in time by the delay of the line. Thus the average current for the entire pulse is zero.

There is a variable attenuator after this point with a maximum ratio of 1 to 16. The maximum allowable signal from this attenuator is 5.0 volts. A power amplifier, with a net gain of 300, supplies a maximum output signal of 88 volts into a minimum load of 1,000 ohms. This section consists of two feedback loops with gains of 15 and 20 respectively. Each loop incorporates limiting circuits to prevent grid current changing of coupling capacitors.

This amplifier has a rise time of 0.2 μsec and will operate with as much as 50 times overload if the pileup of pulses at the input is less than four volts. A 22-kev pulse was not measureably altered by pulses from a rapidly varying intensity Co^{60} source.

A 60-channel electron beam pulse amplitude analyzer, by F. M. Porter and C. J. Borkowski, Oak Ridge National Laboratory, Oak Ridge, Tenn. Conventional multichannel pulse-amplitude analyzers are subject to drifts in channel widths due to relative variation in channel boundaries. The beam-deflection tube described has channel positions dependent on mechanical dimensioning.

A typical tube is shown in Fig. 6. The electron beam is

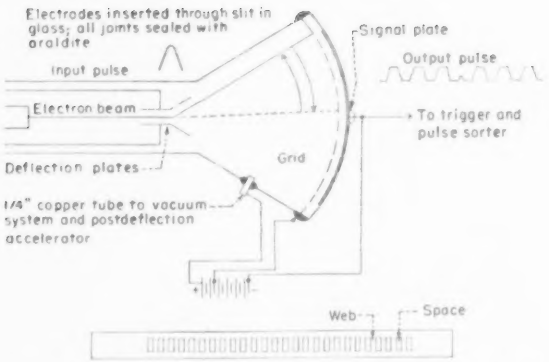


FIG. 6. Typical electron-beam tube used for pulse-amplitude analysis (Porter and Borkowski)

deflected across a target grid having equal webs and spaces. Each time the beam passes a space in the grid, a current pulse is obtained at the signal plate. This plate has a secondary-emission ratio of approximately 6, providing a modest current gain.

The deflection tube in the present analyzer has a target grid with 30 webs and 30 spaces. When used as a 30-channel analyzer, a web and a space define a channel, but 60 channels are available if the channel is defined by either a web or a space. Somewhat better stability and more uniformity in channel width is obtained when a web and a space define a channel. Thus channel-width uniformity is within $\pm 3.5\%$ on 60 channels and $\pm 1.5\%$ when 30 channels are used.

Deflection sensitivity of this tube with a 2,000-volt accelerating potential is 35 volts per inch of deflection. There are four beam diameters per volt deflection.

Figure 7 shows a block diagram of the over-all system. A signal from the detector is fed through a linear amplifier, gate circuit, pulse shaper, and finally to an amplifier that drives the deflection plates of the beam tube. Pulses from the signal plate are counted by a fast binary scaler that serves as a discriminator by means of a decoding matrix consisting of germanium diodes. A pulse is transferred to one of 60 storage channels that corresponds to a given state of the binary scaler. Storage facilities consist of scales-of-16 followed by a mechanical register. Control circuits are introduced to prevent a pile-up of pulses in the deflection circuit before a pulse has been analyzed. When used as a 60-channel analyzer, the system is capable of a 10-μsec resolving time.

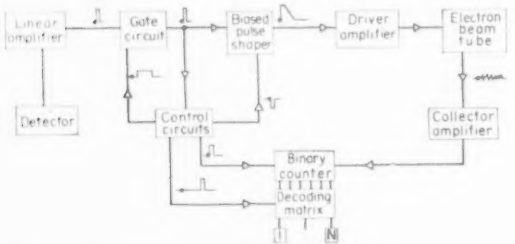


FIG. 7. Block diagram of pulse-amplitude analyzer circuit with electron-beam tube (Porter and Borkowski)

Twin-scintillator method for study of neutrons in presence of gamma rays, by Isadore B. Berlman, Argonne National Laboratory, Chicago, Ill. The method was devised to study neutrons in the presence of a wide energy range of gamma rays. Two organic scintillators were chosen so that the gamma-ray responses are equal, but the neutron responses are different. Neutron measurements are then the difference between the total response of the two detectors.

To obtain identical gamma response, the Compton recoils must be equal. This is expressed by

$$(E_1V_1T_1\gamma\sigma_E) - (E_2V_2T_2\gamma\sigma_E) = 0$$

The neutron response will be given by the difference of the proton recoils

$$(H_1V_1T_1n\sigma_n) - (H_2V_2T_2n\sigma_n) = \text{neutron response}$$

Both equations must be balanced to all factors but proton recoil. To do this: 1. wall effects are eliminated if $T_1 = T_2$; where T is the counting time; 2. edge effects are minimized if $3V_2 > V_1 > V_2$ where V is the scintillator volume; 3. the top surface effect must be minimized; 4. light transmission for the materials must be nearly equal; 5. attenuation must be equal; and 6. multiple scattering must not be too different.

The volumes were chosen such that the total number of electrons in each solution are equal, but the total number of hydrogen atoms differ.

H-xylene (paraxylene) and *F*-Xylene (1,4-bis: tri fluro methyl: benzene) are used. The scintillator added to each is 2,5-diphenyloxazole. The light emission of the two liquids is different. However it was possible to compensate this by: 1. varying the concentration of the scintillator additive; 2. adding quenching agents; and 3. varying the gain of the photomultiplier to compensate finally for small differences.

The Na^{24} and Co^{60} spectra for the two scintillators show excellent agreement. Excitation by a polonium-berillium neutron source is shown in Fig. 8, where the difference between the two curves is the detector response. The detection efficiency in this case is 3.8%. The data was obtained with two RCA 5819 photomultiplier tubes, A-1 linear amplifiers and a 24-channel Marconi pulse-height analyzer. It should be noted that this technique is limited in that low neutron fields can not be detected where there are excessively high intensity gamma fields.

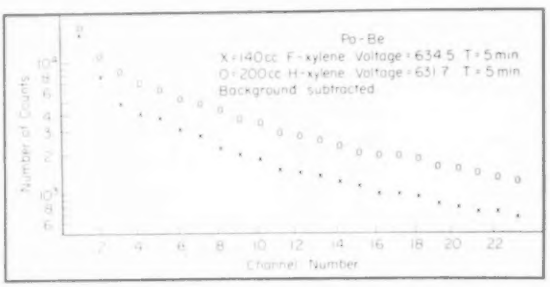


FIG. 8. Twin-scintillator response to polonium-beryllium source. Difference is neutron response (Berlman)

Safeguard Considerations for Nuclear Power Plants

Serious nuclear accidents are highly improbable. Although the violence of such an accident would correspond only to a mild chemical explosion, the fission-product release could compare to that from an atomic bomb. Careful analysis must show that none of a reactor's radioactivity can be dispersed over populated areas

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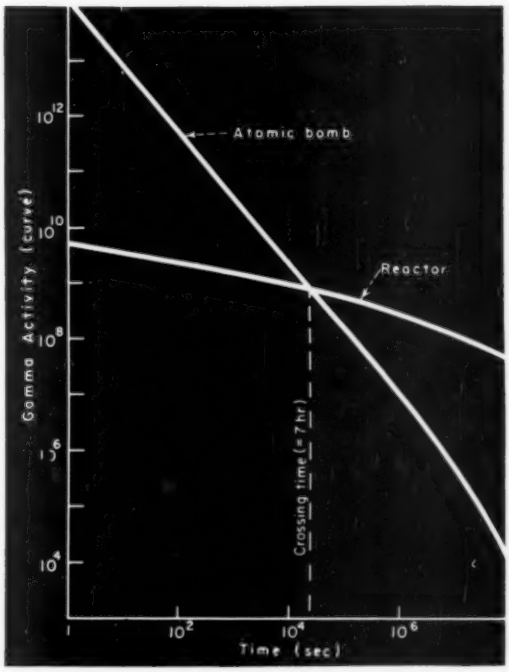


FIG. 1. Fission-product gamma activity after 20,000-ton-TNT-equivalent atomic bomb explosion and after shutdown of 1,000-Mw reactor that has been operating a long time

SAFETY OF THE PUBLIC is an important consideration in design of nuclear power plants. This article presents methods for estimating energy released in a nuclear accident and for evaluating dangers from the dispersed fission products.

Present analysis shows that a serious nuclear accident can occur only as a result of inadequate design, gross equipment failure, and human error. At least two of these factors must be present to cause trouble. Even sabotage cannot easily produce a serious accident in a well-designed plant.

The violent action of an atomic bomb is not a normal characteristic of a chain reaction and indeed is attained only with great ingenuity and effort.

Even if a reactor does get out of control, the nuclear explosion is comparatively minor. As shown in this article, the maximum energy release will be of the order of magnitude of a small chemical explosion. Therefore, a serious reactor accident should be thought of, not in terms of an atomic bomb explosion but rather in terms of the explosion of the gasoline tank in an automobile. In fact, the energy released by chemical reactions that might be initiated by a reactor accident warrant more concern than the energy produced in the nuclear accident itself.

The energy yield likely in nuclear accidents is small enough to make it feasible to contain the emitted fission products by a gas-tight building—providing the building can withstand any associated chemical explosions.

Fission Products

The remoteness of the possibility of a nuclear accident and the modest size of energy release if an accident does occur would make the hazard associated with nuclear reactors completely insignificant were it not for the fission products generated during reactor operation.

Fission products accumulate in the fuel elements of the reactor until they approach the saturated level at which the rate of decay is equal to the rate of production. The saturated activity is about 6 curies of fission-product

* Operated for the Atomic Energy Commission by the General Electric Co.

gamma activity per watt of reactor power.

Since the long-lived fission products have time to build up in important quantities during reactor operation, the decay of fission products after reactor shutdown is less rapid than the decay of the products from an atomic bomb explosion. Figure 1 shows how the total fission product activity decays after a 20,000-ton atomic bomb explosion (*1*) and after shutdown of a 1,000-Mw reactor that has operated a long time. The two activities are approximately equal after 7 hours.

If an accident to a high-power reactor were to cause an appreciable fraction of the fission products to be released, there would be serious hazard to the people living in the vicinity. In addition to the reactor power and fraction of fission products released, the distance to which the hazard extends depends on several factors. These include the form in which the products are emitted from the building, the meteorological conditions at the time of the accident, and the nature of the surrounding terrain.

Figure 2 shows a rough estimate of the gamma-ray dose to an individual in the direct path of the cloud center as a function of distance from the reactor site. The curve is based on an assumed accident to a 1,000 Mw reactor in which 1% of the fission products are released. At distances less than 6 miles the dose exceeds 25 roentgens, which is the minimum dose required to produce detectable changes in the blood (*2*). The pessimistic assumption is made that an atmospheric temperature inversion exists at the time of the accident. This causes the cloud to remain at ground level and limits the rate at which the cloud radius increases as it moves away from the site. On the other hand, the radiation effects due to inhaling long-lived fission products, uranium, and plutonium dispersed in the cloud are not included. These effects may be more serious than the direct gamma radiation from the cloud.

In evaluating the fission-product hazard, it is also necessary to consider the effects of rainout and fallout from the cloud. Evacuation of limited areas and the shutting-off of contaminated food and water supplies may be required when fission products are released.

One means of avoiding hazard to the public from nuclear power plants would be to locate the plants at vast distances from populated areas. But, if reliance for public protection is placed solely on the remoteness of plant sites, the required distances will be so large as to constitute a serious economic handicap to nuclear power. The distances can be greatly reduced by improving the design of reactors to make them more foolproof and sabotage-proof and by providing reactor buildings that would contain any fission products released in a reactor accident.

The use of properly designed reactor buildings for preventing the escape of fission products is made feasible by the comparatively small amount of energy released in a nuclear accident. The biological shield of the reactor will help to protect the building from damage.

Thus, a building of moderate strength having a high degree of gas-tightness will be satisfactory.

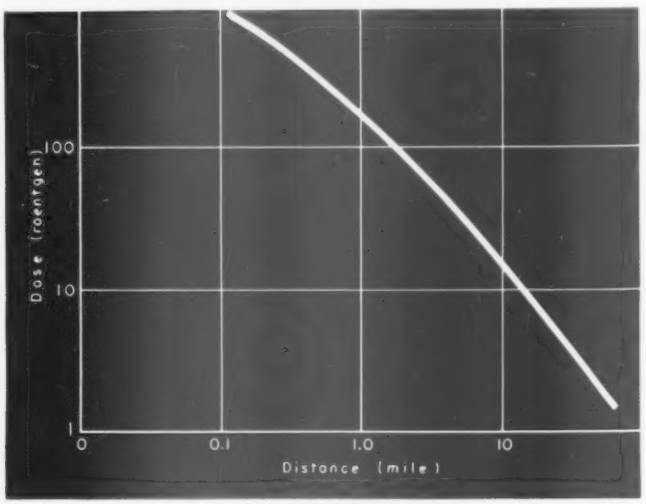


FIG. 2. Gamma-radiation dose to person in path of fission-product cloud after 1% of fission products are released from 1,000-Mw reactor

Reactor Dynamics

The design of the reactor building is determined primarily by the magnitude of chemical explosions that might occur. But it is always necessary to analyze the conceivable types of nuclear accidents so as to establish an upper limit to the possible nuclear-energy release. In the following paragraphs the basic principles for analyzing nuclear accidents will be discussed.

The fundamental measure of the kinetic state of a reactor is the reactivity, k, the average number of fissions produced by the neutrons from a single fission. The reactivity is normally adjusted by control rods, but it also depends on other factors, such as the temperature of reactor parts and the amount of fission-product poisons in the fuel elements.

If the reactivity is held constant at a value greater than unity, the power will increase exponentially, i.e., will be proportional to e^{pt}, where p is the inverse e-folding period. If the reactivity is only slightly greater than unity, p will be small since the power buildup is limited by the time required for the delayed neutrons to be produced. If the reactivity exceeds unity by more than the delayed neutron fraction (about 0.01), the power buildup may occur without the delayed neutrons. The inverse period is then determined primarily by the prompt generation time of the reactor, τ, which is the time required for neutrons emitted in one fission to cause another fission. For thermal reactors, τ is 10^{-4} sec or longer; whereas for a small fast reactor, τ may be of the order of 10^{-7} sec. The difference in reactivity between criticality ($k = 1$) and prompt criticality ($k = 1 + \beta$, where β is the effective delayed neutron fraction) is called "one dollar."

In Fig. 3 the inverse period p is plotted as a function of the amount by which the reactivity exceeds delayed critical for various generation times. A delayed neutron fraction of 1% is assumed. The rapid increase in p when the reactivity passes through prompt critical should be noted. In normal reactor operation, the reactiv-

ity is kept within a few cents of criticality so that the period is of the order of minutes.

A nuclear accident occurs if the reactivity is brought above critical and kept there until the power rises sufficiently to damage the reactor. The accident is usually not severe unless the reactivity is brought close to, or above, prompt critical.

Even if the reactivity is inadvertently raised above critical, damage to the reactor is usually avoided by the operation of safety mechanisms that rapidly reduce the reactivity if either the power level becomes too high or the period becomes too short. The power-level trip circuit is usually set at about 50% in excess of the operating level, whereas the period trip may be set at periods of a few seconds.

The power-level trip is clearly necessary since a gradual power increase to an excessive level could damage the reactor. The period trip circuit is desirable since, if the reactivity is brought far above critical when the power is low, there may not be enough time for the safety mechanisms to function if the trip does not occur until a high power level is reached. In any case, it is desirable that the trip and safety circuits operate with extreme rapidity so that maximum protection is afforded against damage to the reactor.

Safety devices are ordinarily actuated by signals from ionization chambers that measure the neutron flux in the reactor. Much thought, however, is being given to the development of self-contained, "foolproof" safety devices that involve no external circuits and are actuated directly by fissions in the device itself. Once means are devised to surmount the difficulty of periodically testing them, it is likely that much reliance will be placed on such fuse-type devices.

Accident Analysis

In estimating the possible magnitude of nuclear accidents, the pessimistic assumption must be made that, in addition to the malfunction, all safety mechanisms fail to operate.

The accident is considered to occur in two stages. In the first stage, the reactivity is brought above critical by whatever mechanism is causing the accident. Changes in reactivity due to the energy generated in the reactor may be neglected. In the second stage, the reactivity is brought below critical as a result of the energy generated in the accident. This reactivity reduction may occur as a result of thermal expansion, ejection of fuel or moderator from the reactor, or overall disruption of the reactor. In treating this second stage, it is usually possible to neglect further changes in reactivity due to the mechanism that originally caused the accident.

The original reactivity increase may be considered to be either an instantaneous jump in reactivity of an increase at a finite rate. The latter assumption is often more realistic since the second stage of the accident may begin before all the available reactivity can be added to the assembly.

First Stage—Power Rise

While the reactivity is rising above critical, the power level may be written in the form

$$N = N_0 f(t) \exp \int_{t_0}^{t} p(t')dt' \qquad (1)$$

where N_0 is the power at the time t_0 at which the assembly reaches delayed critical, and $p(t')$ is the inverse period corresponding to the reactivity at time t' (3). The function $f(t)$ is a comparatively slowly varying function of time and for slow rates of reactivity increase depends only on the reactivity at time, t. It is usually adequate to assume that $f(t)$ is of the order 10^2 when the reactivity reaches prompt critical.

In a start-up accident in which the reactivity is initially far below critical, the fission rate at delayed critical may be taken to be $S\gamma/\nu\beta$, where β is the delayed neutron fraction, S is the neutron source strength, and γ represents the effective source increase due to delayed neutrons. The factor γ is about 2 in typical cases. Taking S to be 10^7 neutrons/sec, $\nu = 2.5$, $\beta = 10^{-2}$, and $\gamma = 2$, the fission rate at delayed critical is 10^9 fissions/sec, which corresponds to a power of $^1/_{30}$ watt.

To find the value of p when the power reaches a level N, it is convenient to use a simple approximation for $\int p\,dt'$ in Eq. 1. In the region near prompt critical, p is roughly proportional to $e^{\alpha t}$, where

$$\alpha = (d \ln p)/dk$$

The quantity α is inversely proportional to the square root of the prompt generation time and is about 5/dollar for $\tau = 10^{-4}$ sec. Using this approximation, the inverse period when the power reaches N is

$$p = \alpha \frac{dk}{dt} \ln \frac{N}{N_0 f} \qquad (2)$$

For example, if $\alpha \cong 5$, $dk/dt = 5$ cents/sec, $N_0 = {}^1/_{30}$ watt, $N = 1{,}000$ Mw, $f = 100$, Eq. 2 yields $p \cong 5$ sec^{-1}, which corresponds to a reactivity approximately equal to prompt critical. If the control system is designed to give a maximum rate of reactivity increase of 5 cents/sec, the safety system should

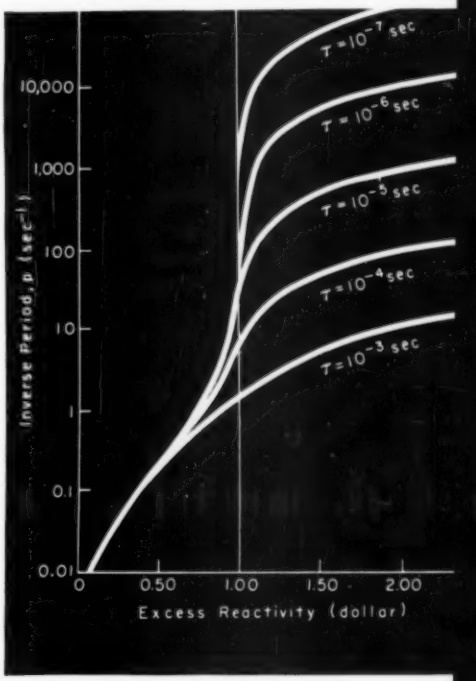


FIG. 3. Inverse reactor period as function of reactivity for reactors with various prompt generation times. Delayed neutron fraction of 1% is assumed

be designed to function in a time of the order of 0.1 sec.

For more rapid rates of reactivity increase, the peak reactivity will exceed prompt critical substantially, so that one can use the approximation

$$p = \frac{\Delta k}{\tau/\beta}$$

where Δk is the reactivity measured from prompt critical in dollars. The inverse period when the power reaches N is

$$p = \left(2 \frac{\beta}{\tau} \frac{dk}{dt} \ln \frac{N}{N_0 f}\right)^{1/2} \qquad (3)$$

If, for example, dk/dt were 85 sec, instead of 5 cents in the preceding case, p would be 140 sec^{-1}, which corre-

sponds to a reactivity almost $81/2$ above prompt critical.

Frequently, one is interested in the value of the inverse period when the energy generated, rather than the power, has reached a specified value. This value may correspond to the energy at which melting or vaporizing of a particular component of the reactor begins to occur. In a situation in which the reactor power is rising rapidly, the energy that has been generated at any time is approximately equal to the power level at that time divided by the inverse period. Therefore, in Eqs. 2 or 3, N must be replaced by E/p where E is the specified energy. This gives implicit relationships for p that may be solved easily by successive approximations since the right-hand members depend only slightly on p.

Second Stage—Power Drop

The analysis of the power-reduction phase of an accident is often complicated by the complexity of the reactor structure. This makes it difficult to decide what mechanism will actually terminate the accident. The most practical approach to this problem is to consider separately the various mechanisms that might be important in reducing the reactivity. It may then be argued that the energy yield when more than one mechanism is effective will be less than the yield if only one of the mechanisms were effective. Simplified mathematical models of the situation are very useful and may furnish almost as reliable upper limits to the magnitude of an accident as attempts to treat the problem in complete detail.

The simplest mathematical assumption is that the reduction in reactivity due to the energy generated is a linear function of this energy. This assumption would apply to reactors with a large negative prompt temperature coefficient, i.e., to reactors in which thermal expansion of reactor components in close thermal contact with the fuel will cause a large reduction in reactivity. This linear relationship would also be effectively correct if the rupture of fuel elements could lead to almost instantaneous removal of fuel from the reactor and if the fraction of fuel elements ruptured at any time is an approximately linear function of the energy generated. The mathematical treatment of the linear case is quite simple and leads to a result independent of the properties of the delayed neutrons. If the reduction in reactivity has the form $\gamma(E - E_0)$, where E_0 is the energy at which the reduction commences and γ is a constant, the total energy yield, E_t is

$$E_t = E_0 + \Delta k_0 \left[1 + \sqrt{1 + \frac{2\gamma E_0}{\Delta k_0}} \right] \Big/ \gamma \quad (4)$$

Here Δk_0 is the peak reactivity, measured above delayed critical, as obtained by the analysis of the first stage of the accident. If E_0 is zero, Eq. 4 implies that the energy generated is just sufficient to bring the reactivity below delayed critical by the amount by which it initially exceeded delayed critical. If the peak reactivity is above prompt critical, the reactivity will be rapidly brought below prompt critical by an amount equal to that by which the peak reactivity exceeded prompt critical. Energy will continue to be generated at a lower rate until the value given by Eq. 4 is reached.

After the reactivity has fallen below prompt critical, the original mechanism that caused the accident may cause the reactivity to rise again. This results in a situation in which the reactivity oscillates around prompt critical until the externally applied reactivity increase stops. If E_0 is zero and the total reactivity furnished by the mechanism causing the accident is sufficient to bring the reactivity Δk_m dollars above delayed critical in the absence of reactivity reduction due to energy generated, then the total energy yield for $\Delta k_m \geq \$1$ is

$$E_t = \frac{\Delta k_m + \sqrt{2\Delta k_m - 1}}{\gamma} \quad (5)$$

In applying Eqs. 4 and 5, care must be taken not to include in γ those components of negative temperature coefficient that occur with a time lag that would make them ineffective in reducing reactivity in an accident. The occurrence of γ in the denominator of Eqs. 4 and 5 points up the advantage of having a large prompt negative temperature coefficient. Since the peak reactivity will never be more than a few per cent above critical, the energy yields given by Eqs. 4 and 5 will only change the core properties by a few per cent and, hence, will be quite modest.

Severe Accidents

In analyzing severe accidents, it may not be realistic to neglect the time lag between the generation of energy and the resulting reduction in reactivity. The kinetic effects leading to the time lags may be related to the inertia of reactor parts or to frictional effects such as the coolant viscosity. In extremely severe accidents, shock phenomena may have to be considered. When kinetic effects must be taken into account, the effects of delayed neutrons are usually unimportant since the peak reactivity is substantially above prompt critical. The equation for the power level, N, then has the form

$$\frac{dN}{dt} = \frac{\Delta k}{\tau/\beta} N \quad (6)$$

Here Δk is the amount, in dollars, by which the reactivity exceeds prompt critical, τ is the generation time, and β is the delayed neutron fraction.

The variation of reactivity with time often may be approximated by an equation of the form

$$\frac{d^n \Delta k}{dt^n} = -f(E)$$
$$E(t) = \int_0^t N \, dt' \quad (7)$$

The order, n, of the derivative is unity when frictional effects predominate and two when inertial effects are most important. The function $f(E)$ relates the pressure that causes the motion of the reactor parts to the energy generated. It is a straightforward matter to integrate the coupled Eqs. 6 and 7 numerically for the appropriate $f(E)$ to find the total energy release.

Even without performing the integration, it is possible to obtain a quite general result by applying dimensional arguments to Eqs. 6 and 7. The total energy generated in the incident will be sufficient to produce a pressure of the same order of magnitude as the constant pressure required to bring the reactivity back to prompt critical in the period corresponding to the peak reactivity.

Suppose that a certain part of the reactor (e.g., the core-reflector interface) must move a distance Δx to reduce the reactivity by \$1. The pressure generated in the accident will be of the order of magnitude

$$P' \approx \frac{\Delta k^3}{(\tau/\beta)^2} \Delta x \rho \quad (8)$$

where Δk is the amount by which the peak reactivity exceeds prompt critical. If $\tau = 10^{-4}$; $\beta = 10^{-2}$; $\Delta x = 1$ in; ρ, the effective mass loading per unit area = 3 lbs/in^2; and $\Delta k = \$1$, the pressure is of the order of magnitude of

10^2 psi. Since the pressure required to overcome mechanical strength will probably be larger than that required to overcome inertia, the pressure will rise to the point where mechanical rupture occurs. Reactivity will then be reduced below critical before much additional energy has been generated.

Even with much larger Δk's and smaller generation times than assumed in this example, the pressure as given by Eq. 8 will be only of the magnitude of the pressure in a mild chemical explosion. Thus, a nuclear accident cannot, in itself, do more than vaporize a small fraction of the reactor core.

It is interesting to note the dependence of the pressure as given by Eq. 8 on the generation time. Since, from Eq. 3, $\Delta k = p(\tau \beta) \sim \tau^{\frac{1}{2}}$, P is proportional to $1/\sqrt{\tau}$. Because of this comparatively weak dependence of pressure on generation time, reactors with small generation times are not much more dangerous than reactors with longer generation times.

Autocatalytic Effects

It has been assumed in the example that the energy generated in an accident tends to reduce the reactivity. This is not necessarily the case; there may be "autocatalytic" effects that increase the reactivity as the generated energy increases. Although such autocatalytic effects can, in principle, greatly increase the magnitude of a nuclear accident, they can usually be shown not to be very serious in practice. The autocatalytic effects are usually quite limited in magnitude and are followed very closely by much larger decreases in reactivity. Furthermore, because of flux variations throughout the reactor core, the autocatalytic effects will not occur "in phase" throughout the core. Thus, the reactivity increases due to effects in parts of the core that are behind in phase will be compensated by the reactivity decreases due to effects in parts of the core that are ahead in phase. When the requirements on a reactor make it impossible to avoid features that might introduce autocatalytic effects, special care is necessary in the design of safety mechanisms and the reactor building.

Conclusion

Properly designed nuclear reactors are easy to control and safe to operate. However, the large quantities of fission products contained in high-power reactors make it necessary to give careful attention to the design of safety mechanisms, the choice of reactor sites, and the construction of the reactor buildings. It must be shown that there is no significant chance for a plant accident to disperse dangerous amounts of fission products over populated areas.

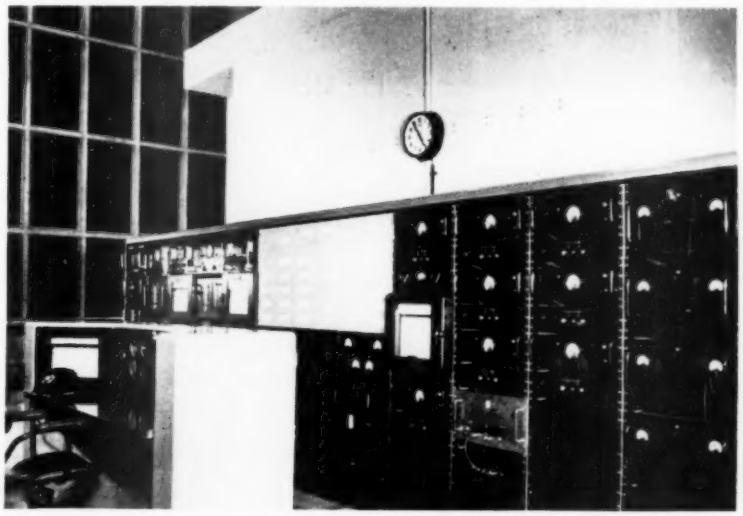
Realistic analyses of what would happen in the event of an accident determine the measures required to adequately protect the public without unnecessarily handicapping the development of the atomic power industry.

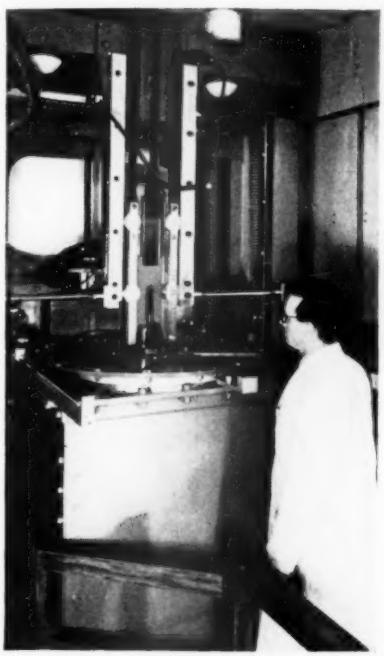
The opinions and conclusions stated herein are those of the author and do not necessarily represent the official position of the Atomic Energy Commission in the field of reactor safeguards.

This article is based on a paper presented by the author at the University of California Conference on Nuclear Engineering, Berkeley, California, September, 1953.

BIBLIOGRAPHY

1. "Assuring Public Safety in Continental Weapons Tests," p. 91 (U. S. Government Printing Office, Washington, D. C., 1953)
2. *Ibid*, p. 113
3. H. Hurwitz, Jr., NUCLEONICS **5**, No. 1, 61 (1949); S. Wallach, Report 13 (Westinghouse Atomic Power Division, Pittsburgh, Pa., 1950)





British Operate Fast Breeder Prototype

The world's only reactor using plutonium as fuel achieved criticality in Great Britain on February 5th.

The unit, known as "Zephyr," operates at 1 or 2 watts. It uses sodium-potassium alloy as coolant and has a uranium blanket. The control room is shown above. Picture at left shows reactor container and lifting gear for removing upper blanket. Other parts of blanket are lowered to make core accessible. Control and safety mechanisms (not shown) are beneath reactor.

Zephyr is the prototype for the first breeder power reactor. It is the fifth British reactor and the first especially designed as a step toward nuclear power.

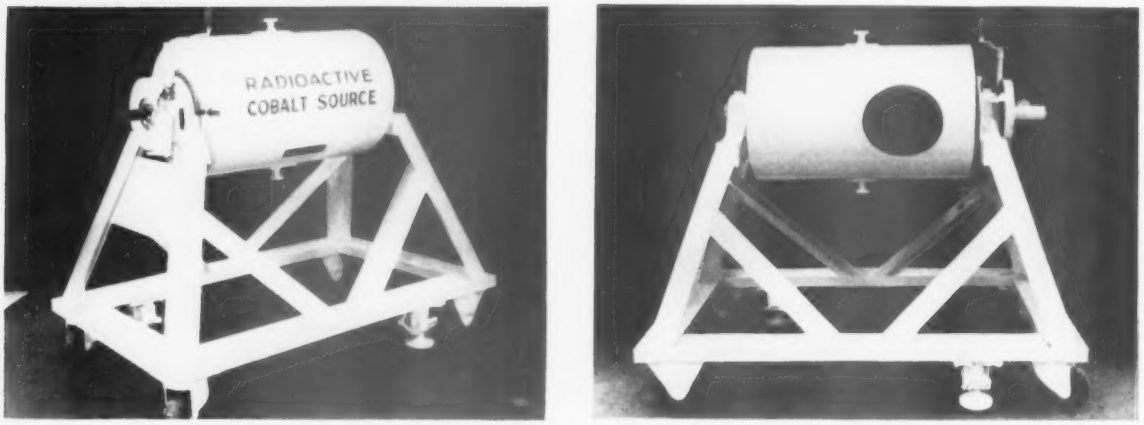


FIG. 1. Cobalt-60 irradiation unit

Design and Performance of a Portable Irradiation Unit

By L. G. STANG, Jr., G. STRICKLAND, A. C. RAND, and G. SELVIN*
The Hot Laboratory, Brookhaven National Laboratory
Upton, New York

At the request of the Medical Branch, Division of Biology and Medicine, U. S. Atomic Energy Commission, the authors designed and had constructed at Brookhaven the portable Co^{60} irradiator described in this article. The original request was rather general and called only for:

1. Source strength of approximately 100 curies of cobalt-60.
2. A flexible mount to permit high-intensity irradiation of small objects close up or low-intensity irradiation of larger animals at distances of 5 to 15 ft or more from the source.
3. Sufficient shielding to reduce the radiation level to tolerance at about 2 meters from the source.
4. Moderate uniformity of radiation field, 15% nonuniformity across a field 6 ft in diameter being permitted.

It was also suggested that we design the shield to accommodate at some later date 250 curies of Co^{60}. The source strength actually used for the present unit was about 135 curies, that being the most convenient to obtain at the time.

Although several types of mount were considered, it quickly became apparent that the most satisfactory one would be a trunion-mounted shield on casters. With the arrangement described later, either a horizontal or a vertical (either upward or downward) beam can be used, depending on the type of object to be irradiated, the most suitable geometric arrangement, the required distance from the source, etc.

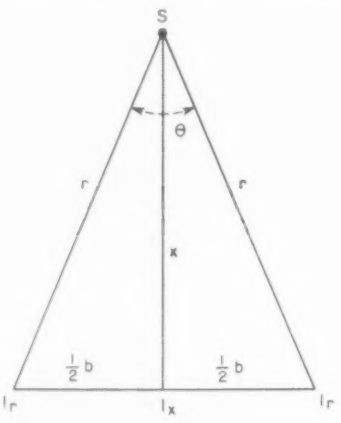


FIG. 2. Geometrical relationships used in calculating extent of uniform field from irradiation unit

It was calculated that 10.8 in. of iron or 6.8 in. of lead would reduce the radiation from a 250-curie point source of Co^{60} to 6 mr/hr at a distance of 3 ft from the source. To reduce the radiation level to 6 mr/hr 10 in. from such a source would require 8.5 in. of lead.

A thickness of 8 in. of lead was actually used. The maximum radiation level found on the surface of the shield was 15 to 20 mr/hr (from the 135-curie source inside).

It was also calculated that the required uniformity could be obtained from a stationary point source. This obviated the necessity of using a more or less uniform plane source or a source that had to be kept in motion during an irradiation.

Description of Unit

The shield surrounding the source is a lead cylinder weighing 3,500 lb mounted with its axis horizontal, 3 ft from the floor. Trunions at each end permit the shield to be rotated about its axis.

The source is attached to one end of a rod that slides along the axis of the shield, through the hollow trunion. In the "safe" position the rod is pushed all the way in, and the source is sur-

* Present Address: Sylvania Electric Products, Hicksville, New York.

rounded on all sides by at least 8 in. of lead. To use the source, the rod is pulled out until it hits a preset stop so positioned that the source is now at the apex of a 45-degree cone cut out of the shield. In this position a beam of radiation is emitted along the axis of this cone perpendicular to the axis of the shield.

Although the shield can be rotated about its axis to any desired angle, a stop bolt is used to confine the shield rotation to one of four quadrants; for use in basement rooms the bolt is located to permit horizontal and downward beams, while for use on the top floor of a building the bolt may be located to permit only horizontal and upward beams. Provision is made to lock the source in the "safe" position when not in use.

The source consists of approximately 135 curies of Co^{60} in the form of three cylinders, each 2 cm long × 1 cm in diameter, packed together in a cup in a triangular "closest-packing" arrangement. For all practical purposes they constitute a point source. The cup is securely screwed to the operating rod, and provision has been made for checking the tightness of this joint.

The unit is shown in Fig. 1.

Performance

Two items of interest were noted after the unit was built. First, because the source is not actually an ideal point source but instead has a finite size, there is some self-shielding that tends to reduce the radiation level in the direct beam. This was demonstrated by the fact that when the source rod was rotated about its own axis, different radiation levels were obtained at a given point in the direct beam—corresponding to more or less favorable geometrical arrangement of the three cylinders actually comprising the existing source. These intensities varied from 84 r/hr maximum to 64 r/hr minimum at 5 ft from the source. The position of the rod giving the highest radiation level in the direct beam was determined empirically and a key and slot arrangement incorporated into the source rod to prevent rotation from this position of maximum intensity. The theoretical intensity for a 135-curie point source of Co^{60} at a distance of 5 ft is 80 r/hr.

The second item of interest was the fact that there was apparently considerable backscatter of soft degraded radiation from the shield around the source. Since this soft radiation is more readily absorbed in air than is the primary beam, and since rays along the edge of the beam have more air to penetrate than those in the center, the beam actually obtained is less uniform than the theoretical pattern. Figure 2, which illustrates this point, shows a plan view of a horizontal beam. The source, S, is located at the apex of an isosceles triangle having legs, r, and a perpendicular bisector, x, from the apex to the base, b. Let I_x be the intensity of the radiation level at the center of the beam, i.e., at the center of the base, and I_r the intensity at each end of the base. For 15% nonuniformity of field I_r can be 85% of I_x. Using the inverse square law, if the distance, x, from the source is 5 ft, then the base, b, of the triangle (width of beam) will be 4.23 ft, and θ, the included angle at the apex, will be 45 deg 32 min.

The uniformity of the direct beam was measured, and for $I_r = 85\%\ I_x$ with $x = 5$ ft, the distance b was 2.5 ft in the horizontal plane and 3.5 ft in the vertical plane. The corresponding angles, θ, calculated from these measurements, were 28 and 38 degrees.

Filtering out the soft radiation brought the θ up to theoretical.

* * *

The authors are indebted to Mr. B. Keene for making the radiation measurements.

Costs and Safe Operation of Modified Irradiation Unit

By JAMES E. McLAUGHLIN, Jr. and HANSON BLATZ
Health and Safety Laboratory, New York Operations Office
U. S. Atomic Energy Commission, New York, New York

The need has arisen for a portable Cobalt-60 shield for use by research workers engaged in the irradiation of biological material. The experimenters require cobalt sources of 200 to 500 curies.* The design described here is patterned after the 135-curie shield built at the Hot Laboratories of Brookhaven National Laboratory and now in use at the Worcester

* For the purpose of shielding calculations, 1 curie of cobalt-60 was presumed to produce 1.35 r/hr at 1 meter. ORNL infers the number of curies from a knowledge of neutron flux, activation cross-section, irradiation time and isotope decay constant. The latter "curie" determines the cost of the cobalt.

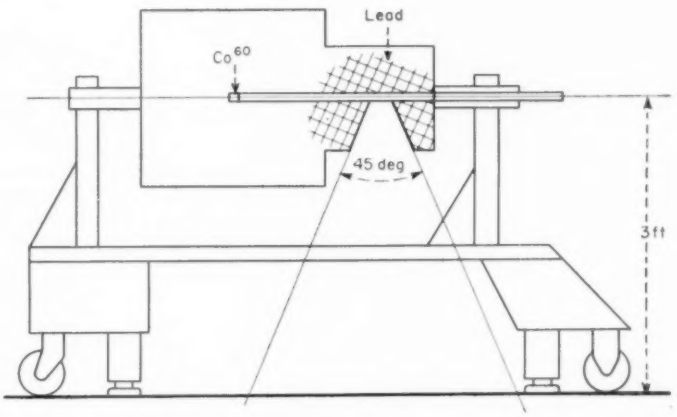


FIG. 1. Modified cobalt-60 irradiation unit

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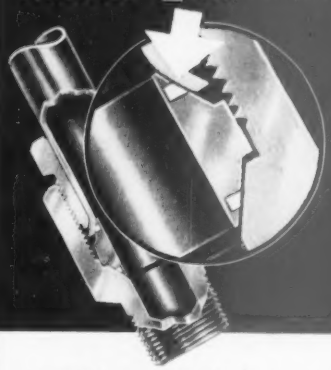

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Foundation of Experimental Biology. The Co^{60} source is located inside a steel pipe that can be moved along the centerline of the cylindrical shield. The radiation port introduces a minimum of scattered radiation and produces fairly uniform radiation fields at convenient distances.

It was found that, as shown in Fig. 1, lead shielding could be reduced from that used in the Brookhaven design. This reduces cost but not safety.

The unique mounting frame permits the use of an unobstructed vertical beam. The unit complies with Bureau of Explosives proposed shipping regulations, as well as the requirements of the Isotopes Sales Department of Oak Ridge National Laboratory. When the unit is in use inside a vault, it is adaptable to a simple, mechanical interlock similar to the one employed at the Worcester Foundation.

The various features of the unit will be discussed further.

Primary Beam

Radiation loss due to self-absorption is considerable in large cobalt sources. For example, if the source is a cylinder 1 in. in diameter, the loss of radiation through the cylinder wall is about 35% (*1*). A more efficient configuration is a thin disk where one of the faces defines the radiation beam. In this case, the self-absorption losses for disk thicknesses up to about $\frac{1}{2}$ in. are quite small. A thin, rectangular shape is more economical relative to the space available inside the source tube. The rectangular configuration used in this unit consists of the appropriate number of cobalt rods of diameter equal to $\frac{1}{8}$ in. and length equal to $\frac{1}{2}$ in. arranged in a rectangular area. Rods of this size are available from ORNL.

Some problems were encountered in evaluating the dose rates in the primary beam of the Worcester Foundation source. Ionization-chamber measurements indicated that lead-scattered electrons add considerably to the total dose. Readings were taken with a 25r Victoreen thimble chamber with and without Lucite caps placed over the thimble. The measurements made with a 1-mm cap were much less than those with no cap (*2*). This decrease indicates the presence of scattered electrons and consequently of gamma radiation less energetic than that originating from the Co^{60}.

An idea of the lower limit of the energy of the scattered gamma radiation can be obtained by a simple calculation (*3*). Assuming that scatter at angles greater than 90 degrees is negligible, the lower energy limit is estimated to be about 0.350 Mev. This suggests that the energies of the electrons may extend up to about 1 Mev.

To reduce the effect of the scattered electrons on dose measurements, and on actual experimentation, a sheet of aluminum $\frac{1}{16}$-in. thick was placed over the radiation port of the modified design. This thickness of aluminum presumably removes electrons with energies up to about 1 Mev and at the same time has little effect on the primary beam.

Safe Operation

Figure 2 shows a typical layout of the installed shield and its interlocking system. Note that the cobalt cannot

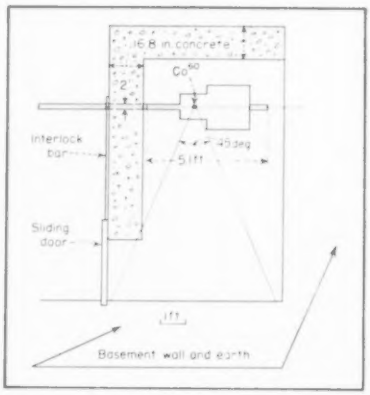

FIG. 2. Typical layout for operating irradiation unit

be inadvertently exposed unless the sliding door is closed, that is, when the hole in the interlock bar is lined up with the 2-in. hole in the concrete wall; i.e., when the source is exposed, the door is locked. Although not exactly to scale, the layout implies the following:

1. The distance from the cobalt, when exposed to the outside surface of the concrete, is about 1 meter.
2. The dose rate outside the concrete is then estimated to be 6.25 mr/hr or less.
3. The dose rate at a point 50 cm from the centerline of the shield is estimated to be 6.25 mr/hr or less, when the cobalt is closed.

At the Worcester Foundation, it was possible to install the shield at one corner of a basement, thereby taking advantage of the earth shield on two sides. A similar kind of vault has been suggested to one AEC research contractor. It is not necessary to install

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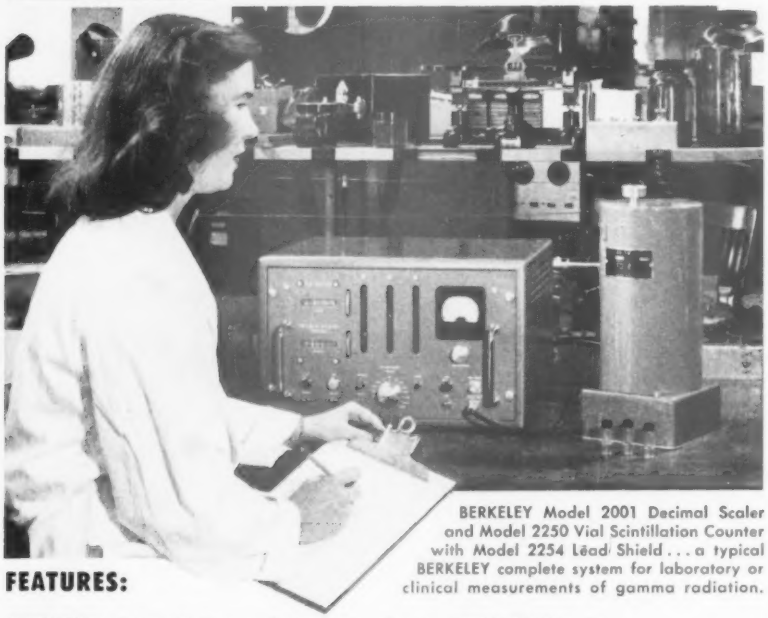

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an elaborate vault door, since the direct beam does not strike the door. In any case, it is often possible to restrict personnel use of the area in the vicinity of the door. Of course, by increasing the distance between the exposed cobalt and the outside of the concrete, less concrete will be necessary.

The unit can be shut down securely by placing a metal cap over the end of the control rod. Provision has been made in the design for padlocking the cap to the shield frame during shipment or shutdown.

Drawings and Cost

Construction details of the unit pictured in block diagram form in Fig. 1 are shown in drawings on file at the Health and Safety Division.

Fabrication of a unit like the one described in the drawings will cost in the neighborhood of $2,500 or less. The costs of the cobalt, transportation of the unit, and construction of a vault will add to this considerably. For example, if a unit is fabricated in New York City, shipped to Oak Ridge, Tenn., for loading and then returned to New York City, the cost of a 560-curie source will be approximately $2,250 for the shield, $200 for transportation, and $3,000 for the cobalt (4). Total cost is $5,450.

* * *

The writers wish to thank L. G. Stang, Jr., G. Strickland, and G. J. Selein of Brookhaven National Laboratory for making available drawings of the original shield. H. J. DiGiovanni of the Health and Safety Division, gave some valuable suggestions about construction details. Finally, we are grateful to Russell Cowing, of the New England Deaconess Hospital, who proposed the interlock mechanism now in use at the Worcester Foundation.

BIBLIOGRAPHY

1. E. Meservey, private communication
2. R. Cowing, private communication
3. G. E. Brown, *Report 2091* (National Bureau of Standards, Washington, D. C., 1952)
4. "Isotopes: catalog and price list" (Oak Ridge National Laboratory, Oak Ridge, Tenn., 1953)

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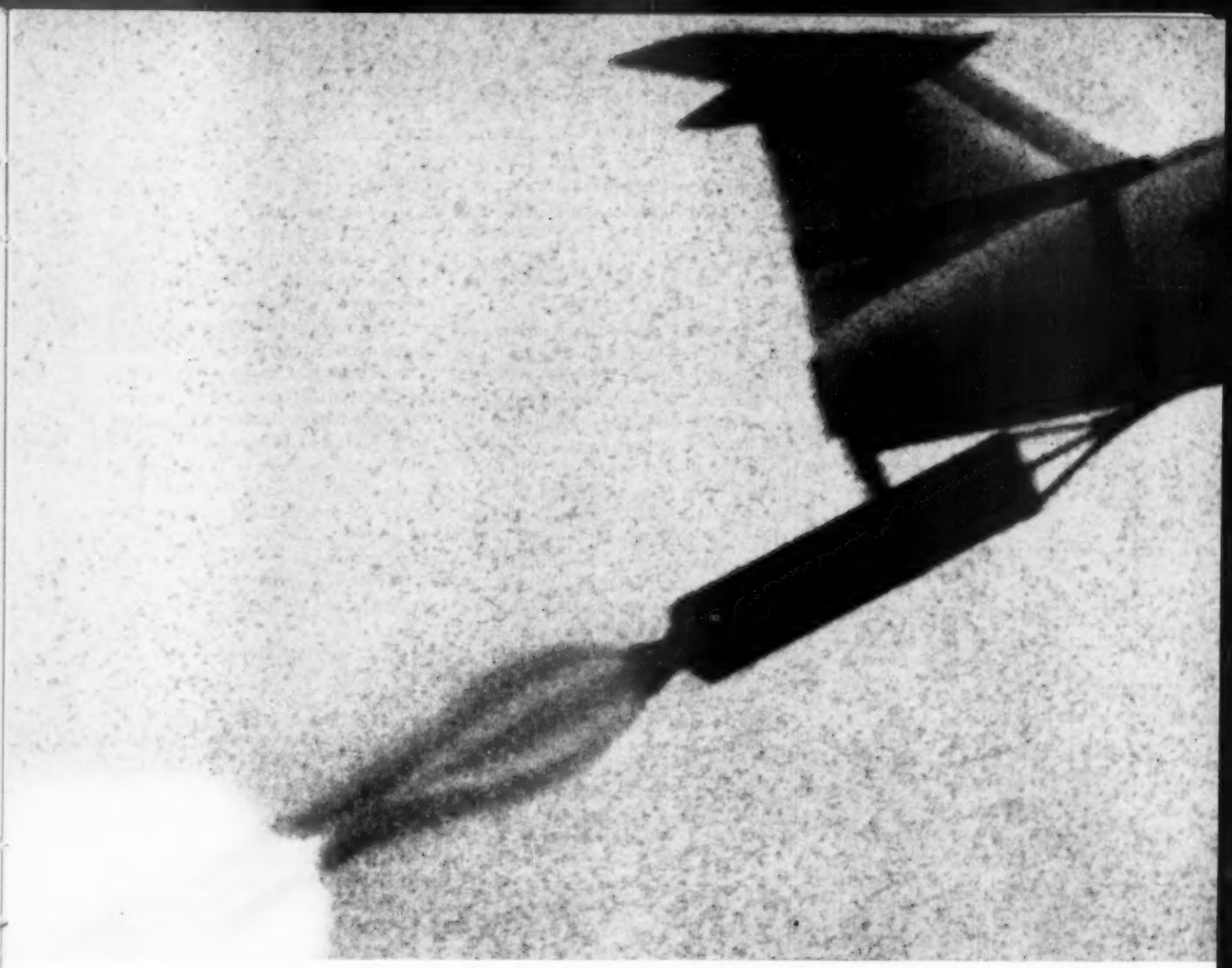

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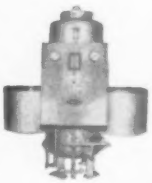

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BOOKS

Scintillation Counters

By J. B. BIRKS (McGraw-Hill Book Co., Inc., New York, and Pergamon Press Ltd., London, 1953, viii + 148 pages, $4.50). Reviewed by ROBERT HOFSTADTER, Department of Physics, Stanford University, Stanford, California.

This book is one of a series of monographs edited by D. W. Fry and devoted to "Electronics and Waves." It is among the first books covering the rapidly advancing field of scintillation counters. It is evident that this book of about 140 pages can only begin to do justice to its very broad and ramified subject. Its scope is further limited because of the author's decision to include a large part of his original research in the volume. In spite of the limitations in size and scope, the author has prepared a very legible and interesting account of the main features of scintillation counters.

The principal parts of the book cover the photomultiplier tube, pulse height and time resolution of scintillations, inorganic scintillators, organic crystalline scintillators, organic plastic and solution scintillators, and applications of scintillation counters. Some rather obvious comments on the treatment of these topics follow below.

The chapter on the photomultiplier tube provides little more than can be obtained by reading the manufacturer's bulletins on the respective tubes. It is typical of the brevity of some discussions that the name of Zworykin appears nowhere in the book, although to Zworykin we owe perhaps the largest debt for the development of the photomultiplier. Secondary emission, the key to photomultiplier operation, is discussed in so little detail that its inclusion in the book seems superfluous.

Pulse height resolution is sketchily treated and, in the reviewer's opinion, is presented in a confused way. The proposed definition of "pulse height resolution" implies a value of 1,000 if 1,000 photoelectrons are emitted from the photocathode of a photomultiplier during a scintillation. To put it mildly, the use of such a definition is open to question. On page 41, the cursory treatment of resolution is further complicated by an unfortunate error in which large C is replaced by small c in the definition of the capacitance of the anode to ground.

While the author's theory of the scintillation process in organic materials appears to have great promise, the correct theory is probably still in question at the moment and the experimental evidence would appear a bit insufficient to merit a definite conclusion. Professor Birk's attempt to understand the behavior of organic scintillations is very much worthwhile, and he is to be commended for carrying it so far.

It is generally desirable to have a book on scintillation counters available to the newcomer in the field and to those interested in the application of scintillation counters to fields such as medicine and biology. For these purposes the present book suffices. To one seriously interested in details, the present book is only moderately satisfactory and serves mainly as an introduction to the bibliography.

Radiations and Living Cells

By F. G. SPEAR (John Wiley & Sons, Inc., New York, 1953, xii + 222 pages, $3.50). Reviewed by DOUGLAS E. SMITH, Division of Biological and Medical Research, Argonne National Laboratory, Lemont, Ill.

This work is intended as an introduction to radiation biology, intermediate between a popular discourse and a standard book for specialists. The chief interest of the author is to present some account of the effects of penetrating radiation on the cells composing human tissues and of how such information is acquired.

The introductory chapter consists of an historical account of radiation biology, which takes the reader from the discovery of X-rays at Würzburg to the use of the atom bomb at Hiroshima. In chapter two the nonbiologist is introduced to the living cell, its structure, division, differentiation, and organization into tissues and organs. A statement of the scope of radiation biology and an introduction to the specific problems of radiation dosimetry, biological indicators of radiation, radiation histology, chemistry and genetics and radiotherapeutics are presented in the third chapter, while the fourth gives accounts of various biological responses to radiation. The next three chapters describe in considerable detail the effects of penetrating radiations on the skin, alimentary canal, generative system and blood and circulatory systems. Chapter eight deals with irradiation of the whole body and the use of atomic energy as a source of penetrating radiation. The use of radiation in cancer therapy is discussed in chapter nine,

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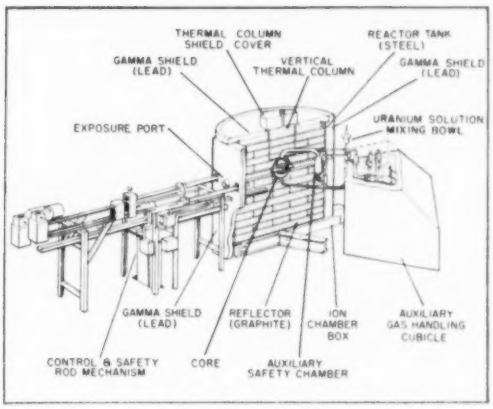

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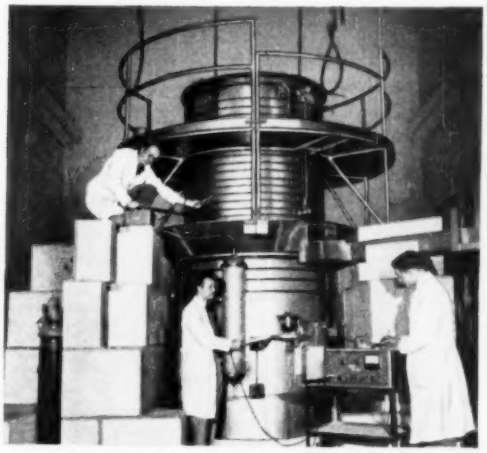

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and in the final section summaries of various theories on the mechanism of action of penetrating radiations on living cells are presented.

Although the book is primarily concerned with the effects of radiation on human cells, it includes many fundamentally significant studies on all kinds of living things. By such references the author clearly establishes the long road that must be travelled through animal experimentation before the goal of human application is reached.

The illustrations are well chosen and of a high quality. The author even demonstrates that the inclusion of a cartoon from "Punch" can be carried out to good purpose in a serious work. Having been written from lecture notes, the book has much of the lecture style which, in general, makes for easy reading. The book falls considerably short of filling the existing need for a complete, up-to-date introduction to radiation biology. Little or no mention is made of many important findings and interpretations which have arisen in recent years, and too much emphasis is given to older work and ideas which have since been extended and modified.

The author's stated purpose is certainly achieved and the book should prove of considerable value to the hospital physicists to whom it was dedicated. The nonphysicist who desires an introduction to radiation biology will find the book understandable and well worth his time. An early chapter on elementary radiation physics would be of great value to the nonphysicists, but there is much helpful material in the concluding chapter. Complete background information is readily gained from a standard physics text. Even the specialist can read this book with profit, for throughout are evidences of the author's years of serious deliberation on the subject, his philosophy of experimentation and his ideas concerning the paths leading toward solution of some of the problems confronting the experimenter.

Theoretical Nuclear Physics

By JOHN M. BLATT and V. F. WEISSKOPF (John Wiley & Sons, Inc., New York, 1952, xiv + 208 pages, $12.50). Reviewed by M. GOLDHABER, Brookhaven National Laboratory, Upton, New York.

Nuclear physics is a far from "finished" branch of science. We must be grateful, therefore, when two physicists, who are making as important contributions in this field as are J. M. Blatt and V. F. Weisskopf find time to look back,

in order to report what has been achieved so far.

In their book "Theoretical Nuclear Physics," they set themselves the task of condensing into one volume the results (especially of the last two decades) of work on "classical" nuclear physics —that part of nuclear physics which involves energies well below meson production thresholds. In this they have well succeeded, in particular also from a pedagogical point of view.

The approach adopted by the authors is systematic rather than historical. They deal not only with general ideas and their mathematical formulation but compare the results with experimental data, though in some places this comparison might profitably have been more detailed.

Several ideas are developed further than had previously been done, in particular the theory of nuclear reactions and the interaction of nuclei with electromagnetic radiation. Some other important topics covered include: general properties of nuclei in their ground state; the two-body problem in all its ramifications; the general nature of nuclear forces and an attempt to understand saturation; nuclear spectroscopy and nuclear models, including a simple discussion of the Wigner supermultiplet theory; alpha and beta decay. We may hope that with time, as we understand nuclei better, it will prove possible to condense the material further. The book is very well produced and appears remarkably free of misprints. It should prove invaluable to teachers, researchers and advanced students interested in some or all aspects of nuclear physics.

BOOKS RECEIVED

Progress in Cosmic Ray Physics, Vol. 2, edited by J. G. Wilson, Interscience Publishers, Inc., New York (North-Holland Publishing Co., Amsterdam), 1954, xi + 322 pages, $8.50. *(To be reviewed.)*

Dislocations in Crystals, by W. T. Read, Jr., McGraw-Hill Book Co., Inc., New York, 1953, xvii + 228 pages, $5.00. *(To be reviewed.)*

Introduction to Experimental Physics, by W. B. Fretter, Prentice-Hall, Inc., New York, 1954, viii + 349 pages, $9.00. *(To be reviewed.)*

Planning Guide for Radiologic Installations, by the Committee on Planning of Radiologic Installations, Commission on Public Relations, Amer-

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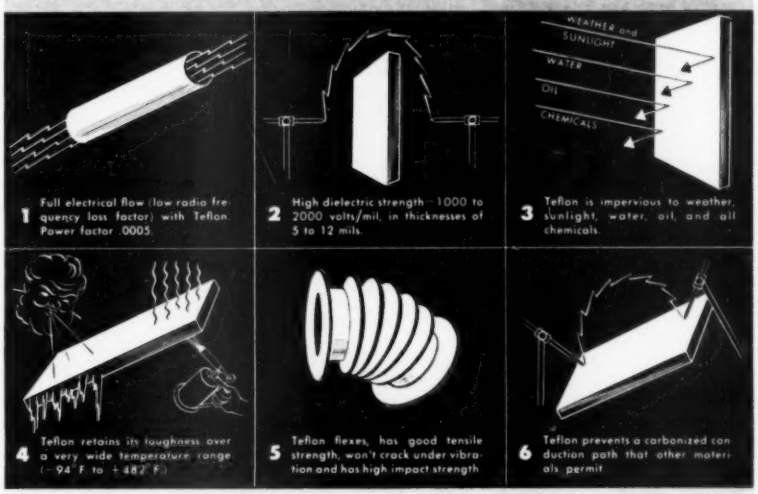

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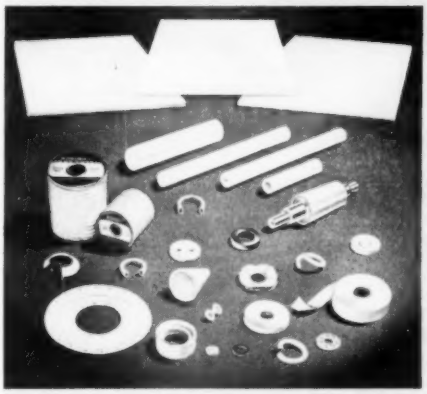

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ican College of Radiology, The Year Book Publishers, Inc., Chicago, 1953, xvi + 336 pages, $8.00. (*To be reviewed.*)

Energy in the Future, by Palmer C. Putman, D. Van Nostrand Co., Inc., New York, 1953, x + 556 pages, $12.75. (*To be reviewed.*)

Nuclear Theory, by Robert G. Sachs, Addison-Wesley Publishing Co., Inc., Cambridge, 1953, xi + 383 pages, $7.50. (*To be reviewed.*)

Annual Review of Nuclear Science, Vol. 3—1953, edited by James G. Beckerley, Annual Reviews, Inc., Stanford, 1953, x + 412 pages, $7.00. (*To be reviewed.*)

Nuclear Moments, by Norman F. Ramsey, John Wiley & Sons, Inc., New York, 1953, x + 169 pages, $5.00. (*To be reviewed.*)

Neutron Optics, by D. J. Hughes, Interscience Publishers, Inc., New York, 1954, vii + 136 pages, $2.50. (*To be reviewed.*)

The Atomic Submarine and Admiral Rickover, by Clay Blair, Jr., Henry Holt and Co., New York, 1954, 277 pages, $3.50. (*To be reviewed.*)

Nuclear Physics, by W. Heisenberg, Philosophical Library, New York, 1953, ix + 225 pages, $4.75. (*To be reviewed.*)

Thermionic Valves—Their Theory and Design, by A. H. W. Beck, Cambridge University Press, New York, 1954, xvi + 570 pages, $12.00. By providing a theoretical account of the behavior of thermionic high-vacuum devices, the author intends that this book should be of use to those doing postgraduate work in electronics. The three major divisions of the book are *The Physical Theory of Electronics, The Mathematical Theory of Electronics,* and *Types of Valve.*

Advances in Electronics, Vol. 5, edited by L. Marton, Academic Press, Inc., New York, 1953, xi + 420 pages, $9.50. Included in this book are chapters on *Performance of Detectors for Visible and Infrared Radiation, Beta-Ray Spectrometers, Solid-State Luminescence, Thorium Oxide and Electronics, Steady-State Theory of the Magnetron,* and *Junction Transistor Applications.* Cumulative author and subject indices are given for the first five volumes of the series.

Space Travel—An Illustrated Survey of Its Problems and Prospects, by K. W. Gatland and A. M. Kunesch, Philosophical Library, New York, 1953, 205 pages, $4.75. A short section is devoted to the application of nuclear reactors to rocket propulsion. The methods considered are: pumping the working fluid directly through the reactor; mixing the nuclear fuel with the working fluid in a combustion chamber; and propulsion by an electron beam, the electron-accelerating power furnished by the reactor.

Crystal Growth and Dislocations, by A. R. Verma, Academic Press, Inc., New York (Butterworths Scientific Publications, London), 1953, xii + 182 pages, $5.00. This book surveys recent developments in the field of crystal growth, with special reference to the spiral growth of crystals. The experimental results obtained by the application of the techniques of electron microscopy, phase contrast microscopy, and multiple-beam interferometry are described.

ALSO OF NOTES

Precautions in the Use of Ionising Radiations in Industry, issued by Factory Dept., Ministry of Labour and National Service. The pamphlet discusses applications made of radioisotopes in industry, and goes on to describe the harmful effects of the various radiations. The main part of the document is concerned with the formulation of a code of behavior that should be adopted by industrial workers. *Press Office, Ministry of Labour and National Service, 8, St. James's Square, London, S.W.1, England, $0.28.*

Tables of Coefficients for the Numerical Calculation of Laplace Transforms, National Bureau of Standards Applied Mathematics Series 30. The tables serve to facilitate numerical evaluation of infinite integrals expressible in Laplace transforms, such as arise in the theory of heat condition and in various branches of electrical engineering. *Government Printing Office, Washington 25, D. C., $0.25.*

Unclassified Bibliographies of Interest to the Atomic Energy Program (TID-3043). This compilation, made by P. E. Postell and H. E. Voress, contains references to bibliographies prepared by the AEC and by commercial, scientific, and other organizations. The bibliographies are arranged by subject. Table of contents and author index are included. Because of the general availability of bibliographies

accompanying the various sections of the "National Nuclear Energy Series," they are not included in the present compilation. The inclusion of a bibliography in this compilation does not insure its availability. *Office of Technical Services, Department of Commerce, Washington 25, D. C., $0.55.*

Decontamination—A Literature Search, by R. L. Curtis. Removal of radioactive contaminants from various materials is discussed with references to the unclassified literature. Seventy references were selected out of a search that included "Nuclear Science Abstracts," vols. 1–8 (through April, 1953); library of the Y-12 plant, Carbide and Carbon Chemicals Co., Oak Ridge, Tenn.; Y-12 reports catalog; Cumulative Book Index; and "Chemical Abstracts," vols. 1–46 (1952). *Technical Information Dept., Y-12 Plant, Carbide and Carbon Chemicals Co., Oak Ridge, Tenn.*

Data for X-Ray Analysis; Vol. 1, Charts for Solution of Bragg's Equation; Vol. 2, Tables for Computing the Lattice Constant of Cubic Crystals. Volume 1, by W. Parrish and B. W. Irwin, contains 85 charts for the K_α wave lengths of chromium, iron, cobalt, copper, and molybdenum. The d-spacing can be read directly to 0.01 Å in the θ range 3–18 deg and to 0.001 Å at higher angles; θ can be read directly to 0.01 deg. Volume 2, by W. Parrish, M. G. Ekstein and B. W. Irwin, together with a good table of $\sin\theta$, is sufficient to compute the lattice constants for copper, nickel, cobalt, iron, and chromium. *North American Philips Co., Inc., Research and Control Instruments Div., 750 S. Fulton Ave., Mount Vernon, N. Y., $2.00 each.*

A Glossary of Terms in Nuclear Science and Technology. As a preliminary edition ("Proposed American Standard"), the "Glossary" was prepared in accordance with procedures recommended by the National Research Council Conference on Nuclear Glossary. The nine sections, which present terms and definitions generally peculiar to their fields, are: *Physics, Reactor Theory, Reactor Engineering, Chemistry, Chemical Engineering, Biophysics and Radiobiology, Instrumentation, Isotopes Separation,* and *Metallurgy.* A comprehensive index covers all the sections. *The American Society of Mechanical Engineers, 29 W. 39th St., New York 18, N. Y., $7.00.*

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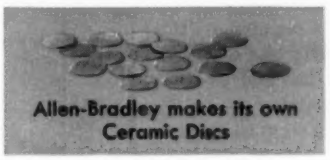

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NEWS

President Calls for Changes in Act To Foster Industrial Participation

Because economic industrial nuclear power "is clearly in sight," President Eisenhower, in a special message to Congress last month, recommended that the Atomic Energy Act of 1946 be amended to encourage industry "to assume a substantially more significant role." The President said that "if the way were open for private investment" industrial companies "would increase their efforts significantly."

At the same time, Mr. Eisenhower asked for important changes on release and handling of classified information, particularly as the act relates to foreign nations.

Interim Changes

In the area of industrial participation in the domestic program, it appears that the President's request conforms quite closely to the recommendations made by the Atomic Energy Commission last year (NU, June '53, p. 88). This includes AEC's desire for the amendments to be interim in nature and to vest considerable responsibility for interpretation and implementation of the law in the hands of the Commission.

Amendments

The specific amendments proposed would:

1. Relax statutory restrictions against ownership or lease of fissionable material and of facilities capable of producing fissionable material.

2. Permit private manufacture, ownership and operation of atomic reactors and related activities, subject to necessary safeguards and under licensing systems administered by AEC.

3. Authorize the Commission to establish minimum safety and security regulations to govern use and possession of fissionable material.

4. Permit the Commission to supply licensees special materials and services needed in the initial stages of the new industry at prices estimated to compensate the Government adequately.

5. Liberalize the patent provisions of the Act, principally by expanding the area in which private patents can be obtained to include the production as well as utilization of fissionable material, while continuing for a limited period (five years) the authority to require compulsory licensing.

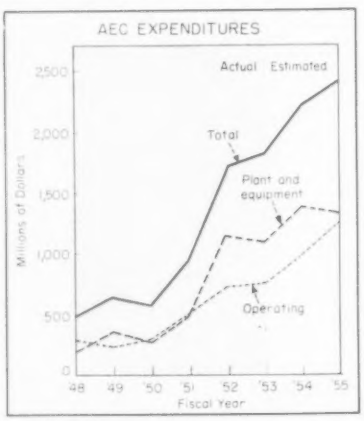
Secrecy

On the subject of classified information, the President made the following requests:

1. That the AEC be permitted to determine the degree of sensitivity of the various categories of classified information and be permitted to give industry wider access to the less sensitive data.

2. That it be possible for the AEC, in cooperating with friendly foreign nations, to exchange certain "restricted data" on the industrial applications of atomic energy and also "release fissionable materials in amounts adequate for industrial and research use."

3. That the President should be enabled to authorize the AEC to permit U. S. citizens or corporations to engage directly or indirectly in the production of fissionable material outside the United States.



TOTAL AEC EXPENDITURES have been rising, but capital spending has peaked and is decreasing in the wake of production facility expansion that causes operating costs to go up

Business Considers Atomic Energy Future

A meeting on business opportunities in atomic energy will be held March 15 and 16 in the Hotel Biltmore, New York, under the sponsorship of the Atomic Industrial Forum, Inc.

Subjects to be covered in the various sessions of the two-day meeting are: radioactive products for use in industry today, new metals and materials, possible future uses of atomic energy in industry, research facilities available for industrial use, consulting services and nuclear engineering services, government functions affecting business opportunities, and products required by the atomic energy program.

Details can be obtained from Atomic Industrial Forum, 260 Madison Ave., New York City.

Nuclear-Powered Aircraft Facilities to Be Built

Plans and specifications for construction of buildings and service facilities for the initial engine test area of the Aircraft Nuclear Propulsion Project at the National Reactor Testing Station were issued last month.

The test area will be the second phase of construction of facilities for ground testing a prototype aircraft propulsion reactor (NU, March '53, p. 71). Utah Construction Co., Salt Lake City, last March was awarded a contract of about $4.6-million for construction of an assembly and maintenance area and an administrative area.

The ground test facilities are being constructed at the same time research and development work, primarily on nuclear phases, is being carried on at laboratories elsewhere.

This new $2.5–3-million contract will be awarded to one bidder. Buildings to be constructed include a control and equipment building, test building, guard house, unit substation, fuel transfer pumphouse and tank building.

PWR Design Calls for 900-million Btu/hr; Projected Power Reactor Will Produce 600 psia Steam

Expected performance of the first central-station nuclear plant in the U. S. can be derived from recently divulged figures. Design of the pressurized water reactor (PWR) planned for this plant calls for at least 900-million Btu/hr to be developed in the reactor. This is about 250 Mw; coupled with the previously announced 60-Mw electrical capacity (NU, Dec. '53, p. 70; Sept. '53, p. 78), this figure indicates a gross efficiency of about 24%.

The reactor will produce 600-psia saturated steam at a temperature of 486° F.

These performance figures will probably be exceeded when the reactor attains steady operation. Only slight enrichment of the uranium fuel will be necessary to achieve criticality with the light-water moderator and coolant.

Over-all construction costs are expected to be about $45-million. The electric power generating portion will cost $9-million. Funds are available to begin construction immediately, and the plant is expected to be in operation within four years.

However, no site has been selected to date. Two factors affecting this selection are: An adequate supply of suitable condensate cooling water must be available and intermittent power in large amounts must be sold, absorbed, or otherwise disposed of.

A third factor in site selection involves safety. Although this type of reactor has a negative temperature coefficient and is thus inherently stable, it is not considered desirable to locate it immediately adjacent to large population or complex industrial areas. However, it is not likely that a very large safety exclusion area will be necessary. The exact size will depend on the ability of the structure housing the reactor to contain any radioactive material that might be released by malfunction of equipment (see p. 57), and on the general topographical and atmospheric conditions of the area.

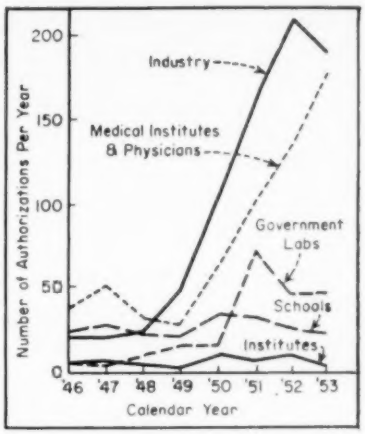
Work on submarine and aircraft carrier reactors has advanced the technology of pressurized water power reactors to the point where AEC feels that this type is the logical choice for the first American central station nuclear power plant. The merits of this decision have been discussed previously (NU, Dec. '53, p. 7).

Principal contractor is Westinghouse Electric Corporation. The firm's responsibility includes all phases of development, design, construction, and testing of the reactor and primary cooling circuit.

After an initial period of experimentation, plans call for a private contractor to have increasing responsibility for the plant's operating schedule.

The Commission is expected to announce soon its selection of contractors and arrangements for engineering and construction of the steam machinery, the electric generating plant, the building housing the reactor, and the other site facilities, for procurement and installation of components of the primary coolant circuit, and for operation of the reactor and associated plant. Industry has been asked to participate in these phases.

It is expected that all of the technical and economic information developed by the participating companies will be made available to the Commission for distribution throughout AEC and to its other contractors. Because of the industrial significance of this project, it may prove to be desirable to release unclassified portions of such information to the public under mutually agreeable arrangements.



GROWTH IN NUMBER of U. S. institutions authorized each year to use radioisotopes is shown by these curves. Isotope sales amounted to $604,901 during fiscal year 1952, $866,273 during 1953

Fixed-Price Bids Asked On Power Package Reactor

The Atomic Energy Commission and the Army will shortly ask for bids from

The Editors Hear

Private industry proposals to participate in construction and operation of AEC's first utility-size nuclear power plant (the PWR) were under study by an evaluation group early this month. Offers from industry were slow in coming in. At least one group that has made an offer felt it would have been impolitic for it not to. The site most frequently mentioned for the reactor is one of the three gaseous diffusion plants. All are under the jurisdiction of AEC's Oak Ridge Operations Office, which doesn't seem overly anxious to get the reactor.

●

Exclusion areas for reactors are determined by the AEC Advisory Committee on Reactor Safeguards. The formula used by this committee was revealed publicly for the first time last month. It is: radius of exclusion area (in miles) = 0.01 Power (in kw). The formula is based on the assumption that if in a reactor accident up to 50% of the fission products are released from the reactor, then personnel within the exclusion area will be exposed to 300 roentgens.

●

The homogeneous reactor experiment at Oak Ridge has borne out the beliefs in the inherent stability and safety of the system. Some feel that the homogeneous reactor of the future will have a thermometer as the primary control instrument. Control would be exercised by varying the amount of water in the core solution; and temperature would be a measure of the fuel concentration. The present reactor will shortly be torn down, and a souped-up, modified version built on its site.

●

Informed sources say that by 1955 the Colorado uranium fields will be on their way to yielding more ore than the Belgian Congo.

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Beta Gauge.....Ra, RaD, Sr^{90}, Tl^{204}
Liquid Level Gauge.....Cs^{137}, Ru^{106}, Co^{60}
Standards.....Alpha, Beta, Gamma

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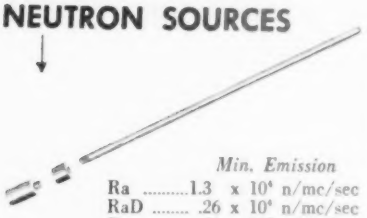

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RaD	.26 x 10^6 n/mc/sec
Po	.26 x 10^6 n/mc/sec

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industry for the construction of a prototype reactor for a "package" nuclear power plant for a remote military location. It is expected that procurement of the power plant will be on a fixed-price contract basis. Up to now, cost-type contracts have been used for all other reactors.

Preliminary letters have gone to a number of companies soliciting information on their interest in the project, their qualifications for the job, and "a relatively detailed description of the performance of the reactor and power plant" that the companies would be willing to guarantee. Replies have been requested by March 20.

The reactor being considered is based on an engineering feasibility and preliminary design by the Oak Ridge National Laboratory. With an electrical capacity of 1,250 kw, the reactor has a core of stainless-steel clad enriched-uranium fuel elements and is moderated and cooled by 1,200 psi water.

The objectives of the project are:

1. To demonstrate that the construction and operation of a particular nuclear power plant permit its use in an arctic environment.

2. To determine exact economic and operating characteristics.

3. To provide a training facility.

On the question of cost, Alvin M. Weinberg, research director of ORNL, under whom the reactor design was done, recently said, "Numerous design studies . . . have shown that with sur-

News Sidelights

Canadian reactor operates again. The NRX reactor at Chalk River resumed operation on February 17th. It had been shut down for 14 months for repairs to damage suffered in an accident (NU, Jan. '53, p. 76; Feb. '53, p. 82; Mar. '53, p. 70).

•

Industry reliance on radioisotopes increases. The Armour Research Foundation of Illinois Institute of Technology used more than 100 times as much radioactivity in 1953 as it did in 1951. This reflects the increased reliance of industrial companies on radioisotopes for solving research and production problems. The Armour Research Foundation used radioisotopes to solve problems in ore separation, muscle composition analysis, wear studies of turbine blades, direct generation of electrical energy, soil permeability studies, and automatic machine control.

•

Congressional subcommittee reorganizes. The Reactor Subcommittee of the Joint Committee on Atomic Energy has been redesignated as the Research and Development Subcommittee and its membership has been increased from five to seven. The group will review AEC and Defense Dept. reactor programs. It will also examine all other research activities in the atomic energy field other than those directly involved in research and development of weapons. Members of the subcommittee are: Representatives Hinshaw, Van Zandt, Durham, and Price, and Senators Knowland, Bricker, and Pastore.

•

Coal company studies nuclear power. The Pennsylvania Coal and Coke Corp. is surveying the company's position to participate in the development of nuclear power for peacetime use.

•

STR installed in Nautilus. Adm. Robert B. Carney, Chief of Naval Operations, stated early last month that the nuclear power plant (the submarine thermal reactor) was to be installed in the Nautilus on Feb. 15th. After commissioning, the Nautilus is expected to perform spectacular feats in a Navy effort to dramatize its need for more nuclear-propelled vessels.

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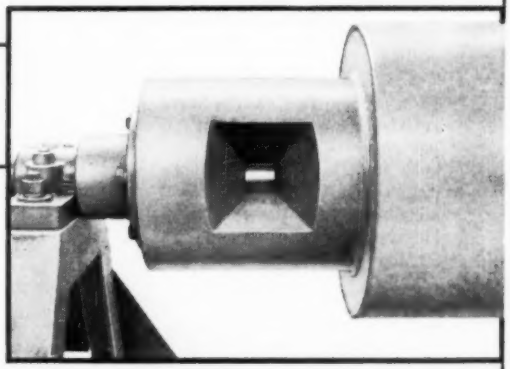

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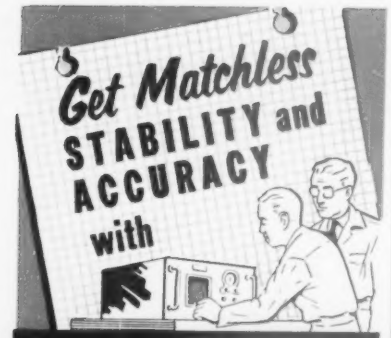

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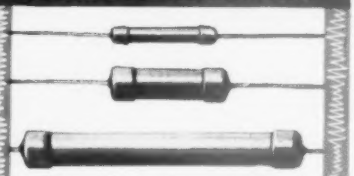

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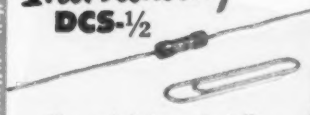

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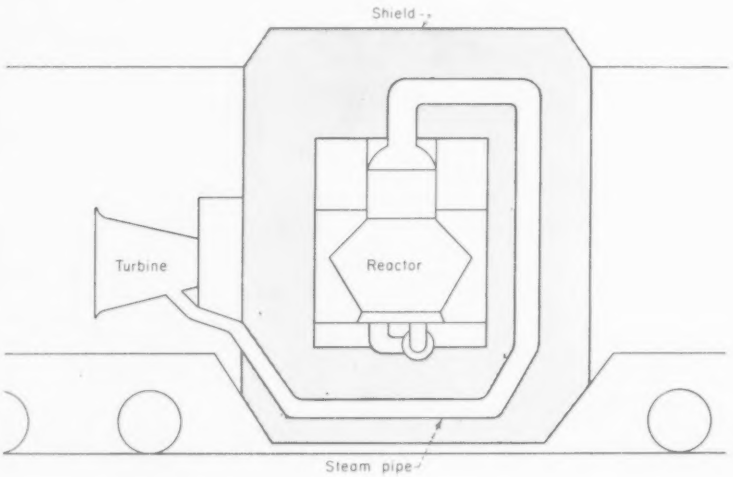
prisingly few design changes small power plants could be built at costs of less than $1,500 per kw. The development for such plants has in large measure been done, and the total cost [for a few megawatts of electrical power] will not be overwhelming—perhaps $2-million."

Construction of the reactor will be at an existing U. S. military base or AEC installation in the continental U. S. The design is to make maximum use of existing technology.

Other design criteria include: *approximate electrical power requirements*—normal full load, 1,250 kw; max. peak load, 1,500 kw; electrical plant factor, 80%; *shut down time*—frequency of refueling, 12 months; maximum shutdown for refueling, 2 weeks; maximum shutdown between refueling, 2 hours; *construction*—the largest fully fabricated component of the plant will be restricted in size and weight to allow for air transportability (about 9 × 9 × 27 ft and 10 tons).



Nuclear-powered Locomotive's Economic Feasibility Questioned by Railroad Men

A one-year study of the use of nuclear energy for locomotive power has shown that, although many problems exist, the method appears to be technically feasible. However, considerable doubt exists as to the short-term economic feasibility.

The study, financed by the University of Utah, was carried out as a graduate course project, under the direction of Lyle B. Borst, professor of physics, with the cooperation of a number of companies.

Cost of building such a locomotive was estimated by the university group to be $1.2-million. This figure does not include engineering or development costs. Based on experience in the locomotive field, railroad men estimate that the cost of the first nuclear-powered locomotive would range up to $120-million (if the unit is built in the near future and if all development costs are applied to it).

Because of security restrictions, no firm idea of uranium costs could be obtained by the study group. If engineering and development costs are neglected, the study group's estimate of fuel consumption of comparable diesel engines seems to run over twice that made by most authorities.

The nuclear locomotive would be a 7,000-hp unit using a 30-Mw reactor. The reactor would be a "water boiler" type with a hexagonal-slab core containing 9 kg of U^{235} in the form of aqueous uranyl sulfate. This fuel would be at a temperature of 460° F. A water reflector would be adjacent to the slab's two faces. The reactor's heat would be removed by reflector water flowing in 10,000 tubes through the soup vessel. The water would be turned to steam at 250 psi (saturated). This would be fed directly to the blades of the steam turbine by means of a circuit similar to that shown in the diagram above. The turbine would

At Oak Ridge, portable tunnels with 3 inch lead walls are used to shield radioactive samples drawn from the uranium-graphite chain reactor. *(Union Carbide & Carbon photo.)*

WHY Oak Ridge USES LEAD FOR LOCAL SHIELDING

At Oak Ridge National Laboratory and other atomic energy installations much of the responsibility for local protection against radiation is placed squarely on lead.

There are four reasons lead has unique value as a local shielding material.

Density is the first of those reasons. At 20° C., lead's density is 11.35, as against 6 to 9 for ferrous metals. For a given level of shielding, lead nearly always proves the *lightest* and least bulky material . . . and that with the most practical balance between ray-stopping power and cost.

The second reason is lead's behavior under radioactive bombardment. It absorbs rays without itself becoming radioactive. Hence lead does not "deteriorate" under repeated attack.

Like most materials, however, lead can be contaminated when radioactive chemicals form salts on its surface. But with lead (and this is the third reason) the radioactive reaction products either break down rapidly or may be easily removed with common solvents. Quick re-use of equipment . . . often within minutes . . . is nearly always possible.

The last reason is that no metal is easier to work than lead . . . a fact with obvious cost and fabrication implications.

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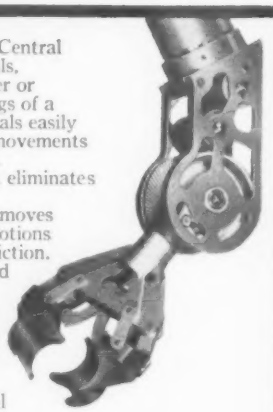

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drive four direct-current generators.

The 2 × 3 × 3-ft reactor (including pumps, steam separator and recombination system) would be surrounded by a 4-ft thick 200-ton shield consisting of alternate layers of steel and a hydrogenous material. The weight of the reactor and shield would be distributed to 12 driving axles by a truss of near bridge-size dimensions. The locomotive would consist of two units having a total length of 160 ft. The reactor and propulsion equipment would be in one unit and air-cooled radiators for the condenser water would be located in the other section.

Engineering problems that have to be faced include: extraction of considerable heat from a small volume, operational stability, leak-proof system, contamination of turbine and consequent difficulty of maintenance, and specialized nature of reprocessing and charging of fuel.

Although railroad men have met this proposal with considerable skepticism, the Association of American Railroads' atomic locomotive committee plans to give the study a searching analysis. It is hoped that they will perform a sufficiently quantitative study that they can define the economic performance conditions under which nuclear power can be useful to the railroad industry.

GE Studying Economics of Industrial Nuclear Power

General Electric Co. is the eighth industrial team to study the economic feasibility of nuclear power for industrial purposes.

Although the firm has had a study underway for months, AEC did not confirm a contract until recently. As with the other teams, the study is privately financed. It is being conducted separately from GE's work on the two submarine reactors.

Besides investigating the economic future of nuclear power production, GE will also consider uses of the products and by-products from various power reactors. The study will be made from the viewpoint of an equipment manufacturer.

AEC Work Employs 13,582 Scientists and Engineers

As of September, 1953, the Atomic Energy Commission and its contractors employed about 77,700 people of which 13,582 were scientists and engineers.

Of this number, 1,561 were biological and medical scientists, 2,476 chemists, 1,704 physicists, 768 other physical scientists, 1,623 chemical engineers, 1,412 electrical engineers, 1,804 mechanical engineers, 448 metallurgical engineers, and 1,786 other engineers.

Unlimited Future Seen for Uranium Industry

"The demand for uranium ore will continue to be great as far ahead as our eyes can see," said Representative Sterling Cole, chairman of the Joint Committee on Atomic Energy, in a January 29th address before the Colorado Mining Association.

He went on to say, "I am deeply convinced that we are today barely scratching the surface in employing atomic energy both in defending our lives and enriching our lives."

After explaining that nuclear weapons are being adopted to all types of tactical situations, Chairman Cole stated, "The day when we will have 'enough' weapons to satisfy the legitimate needs of our armed forces is not in sight. Quite apart from future peacetime needs for uranium and thorium, present and prospective military applications of nuclear energy will by themselves assure a continued high level of demand for raw materials into the indefinite future."

Add to this the needs of peacetime nuclear power plants and it is evident that "the horizons of the uranium industry are virtually unlimited."

In stating that we are not stockpiling raw materials so as to "achieve an unfair advantage when atomic power is a reality," he emphasized that "our foreign ore purchase program is aimed exclusively at acquiring the materials needed to enlarge our stockpile of atomic and thermonuclear weapons—weapons which protect not only this nation but also our friends abroad.".

Radioisotopes Techniques to be Taught Next Summer

Basic techniques in the use of radioisotopes will be taught in three courses to be presented next summer by the Oak Ridge Institute of Nuclear Studies. The four-week courses will begin in June, on July 12, and on August 9.

Information on the courses may be obtained from the Special Training Division, ORINS, Box 117, Oak Ridge, Tennessee.

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LETTERS

How Should Fission Products Be Evaluated?

DEAR SIR:

The problem of evaluating the use of fission products as a source of ionizing radiation is a difficult one at best. However, when an analysis is based on a proposed application and arrangement that is not adjusted to the inherent characteristics of the radiation source, it must lead to pessimistic results. In such a case the difficulty lies not in the problem but in the analysis.

This is felt to be true of the analysis presented by Crean, *et al.* (NU, Dec. '53, p. 32).

In their article, as the result of a *mathematically* correct calculation, they conclude that the variation in dose along diameter of a $2^{11}/_{16}$-in. food can would be so great (10–1 or more from surface to center) as to raise problems of excessively high or low irradiation in one portion if the rest receives the desired amount. This comes about presumably because of two factors. The first is the rapid space variation in radiation intensity. In the second, treating the can as if it were filled with water and using the "narrow beam" half-value layer for 1-Mev radiation in water, namely 4 inches, an additional large reduction in intensity is found.

We believe the conclusion, based on these calculations, that there is a 10–1 attenuation in about $1^1/_2$ inches of material, is in error because the assumed conditions are not correct or appropriate.

In the first place, the can has been placed right next to a line source of radiation. If uniformity of dose is desired, there could be no poorer choice of location. Only by putting the can next to a point source would the variation be more rapid. By the simple expedient of moving a few inches back and irradiating several cans at once, a slowly varying field and equally effective use of the same amount of radiation are achieved simultaneously.

There may be objection if the source is under water. The simple answer is that this is totally unnecessary. We operate a 10-kilocurie cobalt source in air in a shielded room with no particular difficulty.

The question of the 4-inch half-value layer also needs examining. Due to Compton scatter or using the "broad beam" approach, the actual half-value layer in water is 12 inches. This has been shown theoretically and experimentally previously, and we have checked this in our own work.

These points are discussed in a little more detail and experimental results obtained in irradiating 14-inch thick sections of meat are described in a forthcoming article in NUCLEONICS on "Pork Irradiation Experiments Using Cobalt-60 and Waste Fission Products."

—H. J. GOMBERG, L. E. BROWNELL, J. V. NEHEMIAS
Michigan Memorial-Phoenix Project and Fission Products Laboratory
University of Michigan
Ann Arbor, Michigan

AUTHORS' REPLY. The intent of Fig. 2 of our article has apparently been misinterpreted as evidenced in a letter from members of the Phoenix Project. We would like to clarify this intent by stating that we cited Fig. 2 as an example that dosage rate is not constant and not as an optimum geometry for irradiation.

Figure 2 is illustrative of a problem of dosage control that may have to be faced under certain industrial conditions. Such may be the case when a section of a canning line (e.g., canned meat) telescopes a rod source. Such operations usually employ narrow conveyers, and extra space is usually at a premium. As a matter of fact, Figs. 2 and 3 should be used relatively. These figures illustrate that adaption of industrial conveyer systems to a source of radiation will usually require changes in design to achieve dosage control at full production. This statement appears in effect in the last paragraph of the first column on page 34 of the text. The self absorption effect of the high density and high specific activity fission product salts within the rod source has been included in these figures. We wish to clarify that we did not use the geometry shown in Fig. 2 in our calculations, nor do we specify that this is the correct or appropriate choice of location.

It is believed that potential users of fission products in industry would attempt to use a maximum amount of the available radiation field compatible with production rates. The authors agree that there would have to be a compromise in some factors such as dosage rate control, strength of source, and size of installation. It is with the endeavor of attaining full use of the radiation field in the proximity of high-level sources that we have suggested the possibility (in some cases) of surrounding the source with the material being irradiated to a distance of one mean-free-path. This is not the half-value layer but rather the inverse of the linear absorption coefficient. The half layer is equal to 0.693 of the mean free path.

It is true that intervening media, such as water, can be placed between the high-intensity source and the material being irradiated as a method of dosage control. Placing cans farther away from the source would decrease the variation in dose since part of the variation is due to the solid-angle effect. There would be a change in intensity even if there were no absorption (approximately by a factor of the inverse of the distance from the source). The farther the cans are from the source the smaller would be this effect. Optimum use of the radiation would still result in a variation of about 3 to 1 through the target material due to the absorption effect. Excluding the solid-angle improvement, air as an intervening medium for dosage control would be of little value in a large industrial facility because of its low scattering coefficient (3.5×10^{-5} cm^{-1}) over a wide Mev range.

It is true that secondary radiation would further contribute to the absorption of radiation by materials exposed. We have used the simplifying assumption generally accepted as a conservative approximation. This assumption is that the so called "build-up" factor is equal to μA. This amounts to unity at one mean free path. This would be extremely conservative at thicker layers.

We appreciate the difficulties of evaluating the use of fission products as sources of ionizing radiations, and our intent is not to be pessimistic. It is our sincere belief that only out of the research efforts of such organizations as Brookhaven, MIT, and the Michigan Memorial-Phoenix Project will come the solutions to these problems so that industry can best utilize fission products for mankind.

—L. E. CREAN, P. J. ISAACS, G. J. WEISS, F. FAHNOE
Vitro Corporation of America
New York, New York

Tracers and Scrap Steel

DEAR SIR:

In the January, 1954 issue (p. 16) appeared an article by David L. Douglas, entitled "Radioactive Tracers for Tagging Special Steel Melts." NUCLEONICS and the author are to be congratulated for calling attention to this new and potentially useful application of radioactive tracers.

There are, however, certain aspects of the proposal that warrant further consideration. The AEC has been following a very conservative policy in the release of even slightly contaminated metal scrap. This has been done in order not to increase the radioactive content of newly produced metal into which such scrap might find its way beyond the normal content always found in most metals. This attitude has been taken not primarily because of any health consideration but to protect the photographic and nuclear instrument industries.

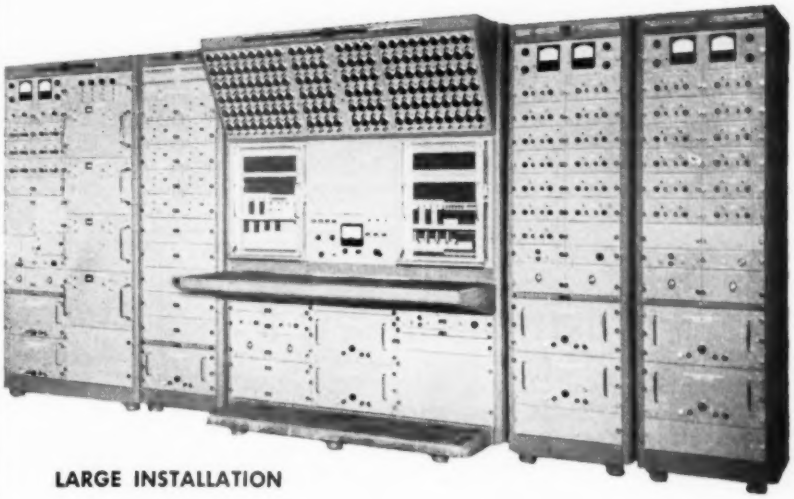
Although the quantity and extent of tracer materials so introduced by the proposed technique would probably be insignificant, users of this method should be made aware of this consideration. Such materials would inherently be less likely to separate from the steel in melting, than the heavier nuclides with which we have been concerned.

On one incidental point, I should like to comment. The value of radiation exposure rate mentioned as "that deemed safe for day in and day out exposure" is actually described by the National Committee on Radiation Protection as that "not expected to cause appreciable bodily injury to the average person." It is important that the common misconception that the Maximum Permissible Exposure is a completely safe exposure be corrected whenever it appears in print. No inference that the technique described is at all hazardous is implied. The exposure rates given are far below the maximum permissible, and exposures would probably be for short periods of time.

—HANSON BLATZ
Chief Radiation Branch
Health and Safety Laboratory
New York Operations Office
U. S. Atomic Energy Commission
New York, New York

READERS submitting comments for publication will aid the editors if they indicate that their letters are intended for this department.

MODERN Problems Demand ... MODERN SOLUTIONS



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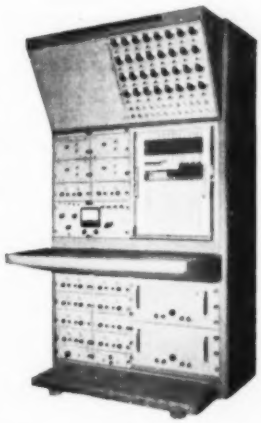
SINGLE PACKAGE COMPUTER

Our Type 16-31R Computer is a single package computer capable of solving differential equations with many simultaneous elements which are often encountered in the simulation of dynamic systems. It contains 20 operational amplifiers, 4 servo multipliers, thirty-two attenuators, all-metal removable problem board, and complete control panel.



PLOTTING EQUIPMENT

For presentation of problem solutions, the Variplotter Plotting Boards provide an accurate inked record. Typical uses include the automatic plotting of: Analog Computer output; guided missile data; engine performance characteristics; and control of manufacturing processes. With accessory equipment the range of applications can be greatly extended.

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PRODUCTS AND MATERIALS

Radiological Electrometer

Baldwin-Instrument Co., England (American agent: Atomic Center for Instruments & Equipment, Inc., 489 Fifth Ave., New York 17, N. Y.). The Baldwin-Farmer radiological electrometer can be used for measuring tolerance dosages, controlling dosages in interstitial radium therapy, and measuring X-ray dosages in body cavities. The instrument is said to be practically independent of variation in battery voltage and in tube characteristics. Dosages can be measured from 0.5 to to 54 r with an accuracy of approximately 1%; an intercavity-type ionization chamber having an accuracy of better than 0.5% extends range to 230 r. (P-1)

Radiation Monitor

Jordan Electronic Sales, Inc., 119 E. Union St., Pasadena 1, Calif. This remote area monitoring system permits measurements from background up to 100,000 r/hr, in several steps, from one to ten remotely located ionization chambers. Low-voltage battery circuit allows operation of chambers up to 5,000 ft from control panel without amplification. Switch-actuated, solenoid-operated shutter in chamber assembly either blocks beta rays or permits them to enter through the 1-mil stainless-steel chamber window. Second solenoid positions Sr^{90} calibration source to assure calibration accuracy of ±5%. With the unit's plug-in construction, monitoring stations may be added. The system is said to be substantially γ-ray independent between 75 kev and 1.3 Mev. (P-2)

Goniometer Specimen Spinner

North American Philips Co., Inc., Research & Control Instruments Div., 750 S. Fulton Ave., Mount Vernon, N. Y. This cylindrical specimen spinner is designed to replace the standard specimen holder of the Norelco wide-range goniometer for X-ray analysis work involving individual analysis of small filaments or the use of sealed capillary tubes. The spinner rotates at 130 rpm, driven by a motor plugged into the X-ray unit. (P-3)

Binary Scaler

Nuclear Instrument and Chemical Corp., 229 W. Erie St., Chicago 10, Ill. The model 183 scale-of-256 scaler has 2-μsec resolving time. Preset-count settings are 10, 100, or 1,000 times the scaling factor. An external model T1 timer permits predetermined-time operation. Built-in timer indicates elapsed time to 9,999.99 min. Internal high-voltage supply provides 500–2,500 volts for Geiger or scintillation detectors. Single switch operates electrical reset of register, timer, and interpolation lamps; unit may be obtained without the timer and with manual reset controls. (P-4)

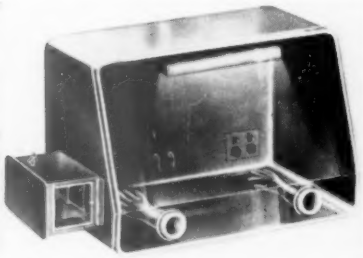
Scintillation Spectrometer

Radiation Instrument Development Laboratory, 2337 W. 67th St., Chicago 36, Ill. The model 2300 scintillation spectrometer automatically sweeps between any two predetermined levels within its range of 0–100 volts, resets, and repeats the cycle. The system consists of (top) model 118 electronic sweep and counting-rate computer, (center) model 115 pulse-height analyzer, (bottom) model 80 high-voltage supply, model 43 scintillation counter, and Brown recorder; each unit may be operated separately. Channel level and counting rate are directly read off meter. Slow and fast speeds are provided for electronic sweep and counting-rate sampling time. The system may be manually operated as a single-channel pulse-height analyzer. Automatic sample changer (changes samples when sweep circuit resets) is also available. (P-5)

Scintillation Survey Meter

Radiac Co., Inc., 489 Fifth Ave., New York 17, N. Y. The model 963 Scintillometer, a portable γ-ray detector, utilizes a 5819 photomultiplier coupled to a scintillation crystal. Output from the tube is pulse shaped by a miniaturized amplifier, integrated and presented on a calibrated meter. With

batteries, the unit weighs 7 lb. Sensitive zone is in a forward and downward direction. The capsulated crystal may be removed from the multiplier tube without disturbing associated circuitry or components. (P-6)



Portable Hood

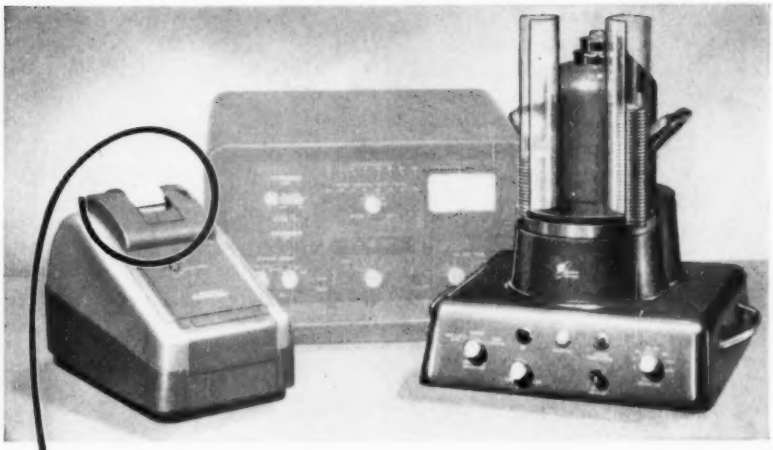
P. M. Lennard Co., Inc., 671 Bergen St., Brooklyn, N. Y. This low-cost, portable, controlled-atmosphere hood is constructed of a chemically inert Fiberglas plastic. Filter system with vacuum pump permits the selection of purification trains to control dust, bacteria and moisture. Any required thickness of lead shielding can be inserted between the laminated layers. Dimensions are 36 in. long, 20 in. deep and 24 in. high. (P-7)

Film-Processing Chemical

General Electric Co., 4855 Electric Ave., Milwaukee 1, Wis. Fixer-Neutralizer, used following the fixing process so that films do not become over fixed, is claimed to cut X-ray film processing time by 50% and to preserve films many years without danger of staining. Washing time is decreased to 5 min; drying time is substantially cut. One gallon of Fixer-Neutralizer, in 4 gal of water, is said to process 1,600–2,000 14 × 17 in. films. (P-8)

Radiation Survey Counter

Müller Nuclear Industries Pty. Ltd., 675 Whitehorse Rd., Mont Albert, Melbourne, Australia. This portable survey equipment comprises G-M counter, head phones, and counting-rate meter. The counter consists of seven counting elements within one glass envelope. This construction is



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You can *automatically* count and record the radioactivity of as many as 50 samples with Nuclear-Chicago's Sample Changer System. Each sample is counted for a preset number of counts after being smoothly moved from the "load" magazine into the *count* position within the lead shield. Shields are available for use with *Nuclear-Chicago geiger, scintillation, or automatic gas flow counters.*

When the preset count is reached, the scaler stops; the printing timer records the sample "identity" number together with the time required to accumulate the preset count; and the changer moves the counted sample into the "unload" magazine while simultaneously moving a new sample into *count* position. After all the samples have been counted, the instrument can be set to (1) shut itself off, (2) take background counts, or (3) repeat the cycle indefinitely if desired.

Nuclear-Chicago scalers are available for use with the changer, or other scalers may be suitably modified. Fifty numbered sample carriers accept 1¼" or 1" by ⅛" sample planchets. Count Selector Switch coupled with scaler's Scale Selector Switch provides a wide range of preset counts. Both sample magazines are clear plastic for easy observation of cycle progress. Expendable sample carriers and the chrome-plated turntable make decontamination simple if necessary. Write for complete details today.

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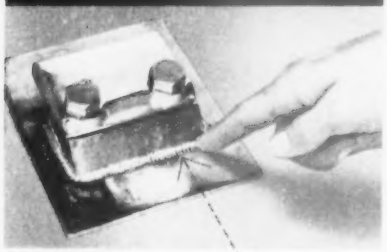

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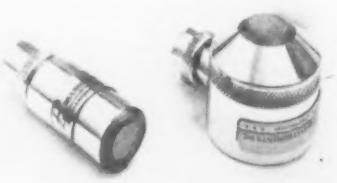
said to increase the gamma-to-background ratio by a factor of 2; background count is about 160 cpm. Active length of the element is 150 mm. Counter tube, amplifier, and batteries are encased in aluminum cylinder 3 ft long and 2 in. in diameter; amplifier is of the cold-cathode type. Head phones provide for rough exploration and the ratemeter for more exact results; both may be used simultaneously. Ratemeter has ranges of ×1, ×2, ×5 and ×10. (P-9)

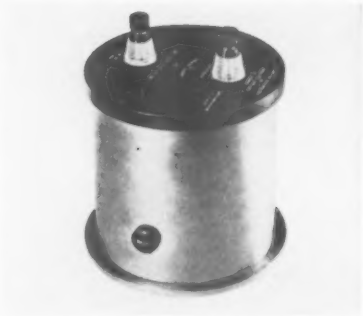
Magnetic Shift Register

Raytheon Mfg. Co., Equipment Engineering Div., 148 California St., Newton 58, Mass. All components of this single-stage 100-kc magnetic shift register are sealed in a plastic case, except the diode which is readily removable. It runs at a power level less than $\frac{1}{4}$ watt per stage at maximum frequency of 100 kc. Output is 16 volts with "one-zero" ratio of 5/1. Minimum-load impedance is 7,500 ohms. (P-10)



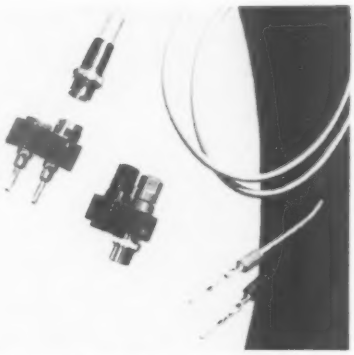
Ultrasonic Probes

Branson Instruments, Inc., 430 Fairfield Ave., Stamford, Conn. These type B crystal transducers are designed as probes for ultrasonic thickness gaging with the Audigage thickness testers. The $\frac{1}{2}$-in.-diameter transducers employ both quartz and barium-titanate ceramic as active elements; sensitivity is said to be approximately that of the $1\frac{3}{8}$-in. all-quartz probes. The transducers are fitted with quartz wearplates. The probes are available in straight or right-angle mountings and are directly interchangeable with standard models. (P-11)



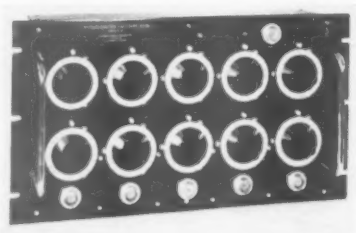
Peak Voltmeter Unit

Sensitive Research Instrument Corp., 9-11 Elm Ave., Mount Vernon, N. Y. The model VPA high-voltage peak unit converts any sensitive research electrostatic voltmeter to a peak-reading voltmeter. Maximum inverse peak voltage is 30 kv. Charging and discharging time constants are 10 μsec and 5 sec, respectively. Frequency range is 60 cps to 10 mc. (P-12)



Conversion Plugs

Millivac Instrument Corp., Box 997, Schenectady, N. Y. The CP-122 and CP-221 conversion plugs permit amphenol-to-spaced jacks and spaced plugs-to-amphenol connections, respectively. They also permit use of a shielded Millivac CL-101 clip lead for old-style meters and scopes. (P-13)



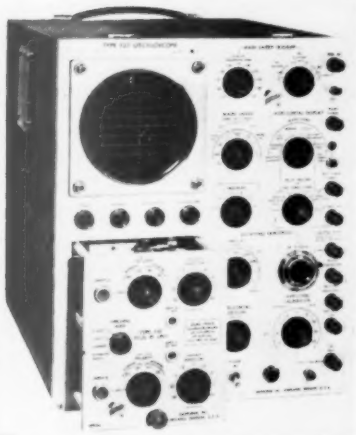
Voltage Divider

Ekco Electronics Ltd., Southend-on-Sea, Essex, England. The potentiom-

eter unit is a 5-channel voltage divider for polarizing G-M tubes; it is intended for use with the Ekco power unit 1033. Each channel is variable in steps of 5 volts from 205 to 1,500 volts, each required output being selected by means of two calibrated controls; a coarse control selects steps of 100 volts and a fine control, steps of 5 volts. Output is accurate, on open circuit, to ±2% of dial reading. (P-14)

Rectifier Tube

Bendix Aviation Corp., Red Bank Div., Eatontown, N. J. The JAN 5993 full-wave, high-vacuum rectifier tube is designed to replace such types as the 6X4 and the 6X4W. Shorts and other effects of shock and vibration are said to be virtually eliminated. The tube can be mounted in any position and utilizes a 9-pin base with electrodes connected to alternate pins. (P-15)



Cathode-Ray Oscilloscope

Tektronix, Inc., Box 831, Portland 7, Ore. The type 535 cathode-ray oscil-

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A new *roentgen calibrated* integrating ratemeter with thimble ionization chambers for many purposes.

A compact control unit for pre-setting and monitoring both rate and total roentgen delivery through a thimble ionization chamber selected for the sensitivity, energy and intensity to be measured.

PROBE SPECIFICATIONS

MODEL	RADIATION SPECTRUM (Kev. effective)	SENSITIVITY RANGES	TOTAL DOSE (roentgens)	USE
601	30 to 400	10-30-100 r/min.	1 to 999	X-ray therapy
602	30 to 400	100-300-1000 r/min.	10-9990	X-ray therapy
603	400 to 2000	5000-15000-50000 r/min.	500-499, 500	On telecurie Gamma sources
604	20 to 50	100-300-1000 r/min.	10-9990	Low energy therapy
605	400 to 2000	1-3-10 r/min.	0.1-99.9	Gamma ray sources
606	400 to 2000	10-30-100 r/min	1-999	Gamma ray sources
607	400 to 2000	100-300-1000 r/min.	10-9990	Gamma ray sources
608	30 to 400	10-30-100 r/hr.	1-999	Survey in vicinity of X-ray machines
609	**Not Applicable**	10-30-100 r/min.	10-9990	Beta-Gamma skin dose
610	I^{131} and Au^{198}	1-3-10 mc. I^{131}	**Not Applicable**	Isotope assay
611	400-2000	0.5-1.5-5 r/min.	0.05-49.95	Gamma ray sources

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A variety of ion chambers, not limited to those tabulated above, provides a wide selection for radiation measurement in research, diagnosis and therapy, health protection, isotope assay, production control and allied fields.

FEATURES

Rapid measurement . . . continuous indication of rate and dose . . . reliability with high accuracy . . . flexibility in use and placement of chambers . . . wide selection of energy, intensity and sensitivity.

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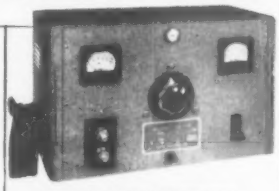

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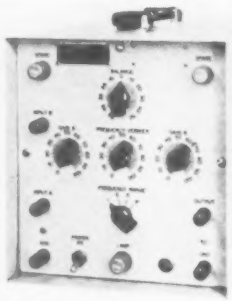
loscope provides 24 sweeps from 0.1 μsec/cm to 5 sec/cm with 5× magnification on all ranges, and continuously variable uncalibrated sweeps from 0.1 μsec/cm to 10 sec/cm. Main-sweep delay is variable from 10 μsec to 20,000 μsec. Trigger selector permits automatic triggering or amplitude selection. Square-wave amplitude calibrator covers range of 0.2 mv to 100 volts. Sensitivity of horizontal input amplifier is 0.2–20 v/cm, continuously variable. Three plug-in preamplifiers are available: 53C dual-trace unit, 53D differential high-gain d-c unit, and 53A wide-band d-c unit. (P-16)

Network and System Analyzer

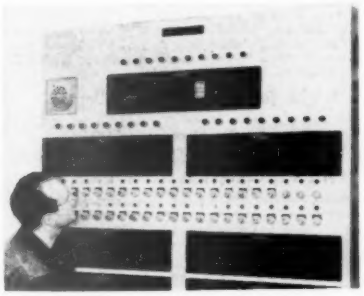
Technology Instrument Corp., Acton, Mass. The Complex Plane Analyzer is an analog computer used for the design of networks and feedback control systems. Applications include vector calculations on the complex frequency plane, simultaneous gain and phase-shift computations, and solutions for open and closed-loop system problems. Up to ten vectors can be multiplied at once; angles can be metered from −3,600 to +3,600 deg and magnitudes from one ten-billionth to ten billion. The unit is battery-powered. (P-17)



Electronic Switch

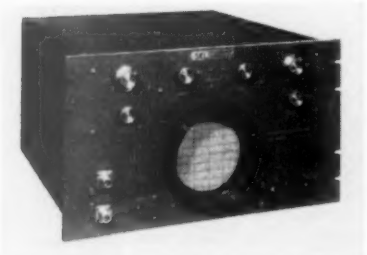
Chatham Electronics Corp., 475 Washington St., Newark 2, N. J. This portable electronic switch permits simulta-

neous observation of two patterns on the screen of a single cathode-ray oscilloscope. Relative positions of the patterns may be superimposed or separated. A square-wave output is available with frequency continuously variable from 10 to 500 cps, amplitude continuously variable to 30 volts (peak to peak), and 25-μsec rise time at 500 cps. The unit's direct-coupled amplifiers are alternately operative and inoperative at a switching rate of 10–2,000 times/sec. Amplifier characteristics are: gain of 10; frequency response within ±1 db from zero to 5,000 cps with amplifier at full gain; 900,000-ohm input impedance, ±10%; input voltage rating, 150 volts, maximum, at maximum attenuation; 50,000-ohm output impedance at full gain; output, maximum, 75 volts (peak to peak), max., at balance. (P-18)



Visual-Sequence Annunciator

Panalarm Products, Inc., 6312 N. Broadway, Chicago 40, Ill. In systems of closely interrelated variables, these visual-sequence annunciators indicate the first variable to go "off normal" in case of system failure. This is accomplished by automatic lock-out of subsequent signals or by causing the first signal to be red and subsequent signals white. Annunciators are available providing 3 to 48 signals. (P-19)



Cathode-Ray Indicator

Spencer-Kennedy Laboratories, Inc., 186 Massachusetts Ave., Cambridge 39, Mass. The model 600 cathode-

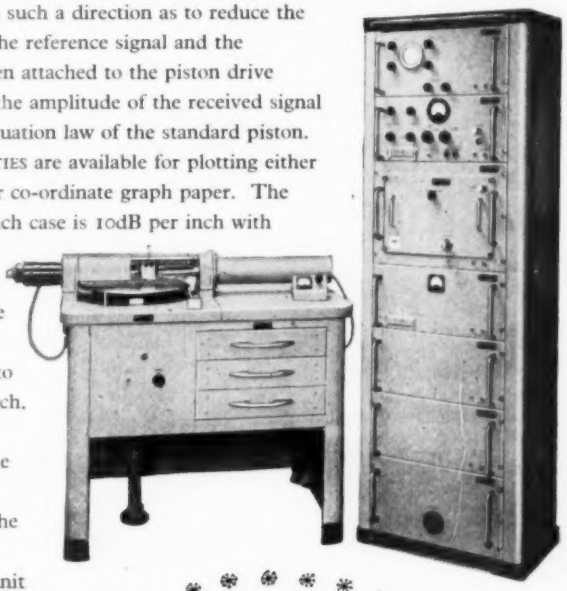
An Equipment for recording

ANTENNA RADIATION PATTERNS

THIS equipment has been developed by EKCO Electronics to automatically record the radiation patterns of any centimetric antenna. The antenna under test is mounted on the roof of a rotatable trailer and illuminated by a fixed transmitter. The amplitude of the received signal is then continuously plotted against the angular traverse of the trailer.

ALL the equipment except the transmitter unit is mounted in the trailer and remote controls for the transmitter are provided. The received C.W. signal is mixed with a modulated Local Oscillator signal and the resultant I.F. output combined with an anti-phase modulated I.F. signal. The reference signal is derived from a 30 Mc/s Oscillator and Servo-driven Piston Attenuator. The combined signals are fed via a seven-stage, low-noise I.F. Amplifier to a balanced Modulator, and the resultant error signal applied to a Servo Amplifier. The output of this Amplifier drives a Servo Motor which moves the Piston Attenuator in such a direction as to reduce the difference between the reference signal and the received signal. A pen attached to the piston drive mechanism records the amplitude of the received signal in terms of the attenuation law of the standard piston.

FACILITIES are available for plotting either on Cartesian or polar co-ordinate graph paper. The amplitude scale in each case is 10dB per inch with a maximum travel of 65dB and the Cartesian co-ordinate paper can be run at rates corresponding to 2 or 5 degrees per inch. THE Standard Equipment covers the frequency range of 9300 to 9500 m/c. The frequency changer section is a plug-in unit and other frequency ranges can be covered to special order.



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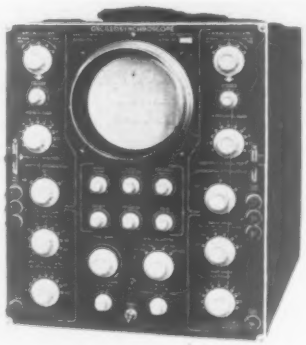
VAN NUYS, CALIFORNIA

ray indicator, designed to be used with the model 610 high-speed sweep generator, enables total writing speeds to 500 cm/μsec. Internal power supply provides 4,000 volts over-all accelerating potential. Provision is made for connection of an additional external high-voltage accelerating supply of up to 25,000 volts. (P-20)

Air Compressor

Cornelius Co., Dept. KP, 550 39th Ave., N. E., Minneapolis 21, Minn. The model 32R1500 $6\frac{1}{2}$-lb air compressor, having a rated discharge pressure of 2,500 lb/in.^{2}, is designed to charge industrial breathing equipment. The 3-stage compressor operates with V-belt drive from a power source of $\frac{1}{2}$ hp or greater. It compresses 70 ft^3 of free air to 2,350 lb/in.^{2} in 100 min and has an ambient temperature range of 0–160° F. (P-21)



Oscilloscope

Browning Laboratories, Inc., 750 Main St., Winchester, Mass. The model OA-16 oscillosynchroscope provides a calibrated buck-out voltage that allows balancing out d-c levels to 10% accuracy so that small superimposed a-c signals can be expanded for inspection; possible expansion is said to be 40:1

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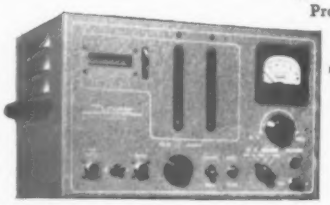
Low-Cost
Precise



Multi-Purpose LABORATORY

POLI-SCALER

The Detectron DS-606 Poli-Scaler is a complete laboratory scaler of exceptional versatility. Adaptable to GM and scintillation counting and frequency checks. Power supply may be used for either GM input or to operate accessory equipment.

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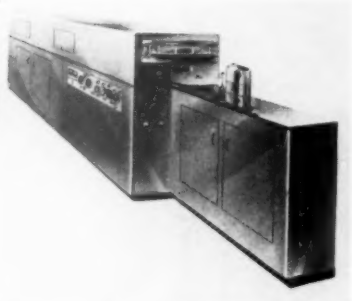
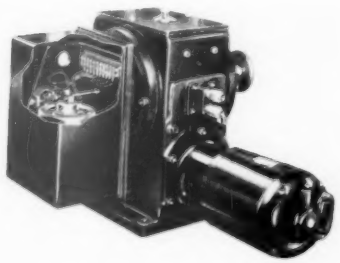


Spectrograph

Jarrell-Ash Co., 26 Farwell St., Newtonville 60, Mass. This plane-grating spectrograph is completely stigmatic and covers 2,000–6,500 Å at a single setting. Theoretical resolving power ranges from 75,000 in the first order to 600,000 in the eighth order. Standard unit is supplied with a 20-in. plateholder, which will accommodate two 4 × 10 in. plates. With a standard 15,000-line in. ruling, the plates cover 2,200–4,700 Å in a continuous spectrum at a dispersion of 5 Å/mm; 7,500- and 30,000-line in. gratings are available. Spectrograph has push-button controls for the shutter, wavelength and plate-racking mechanisms. Spacing of plate-racking mechanism gives spectra 1, 2, and 3 mm apart. Adjustable or fixed slits are optional. (P-23)



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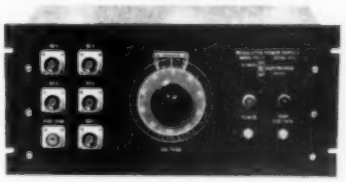

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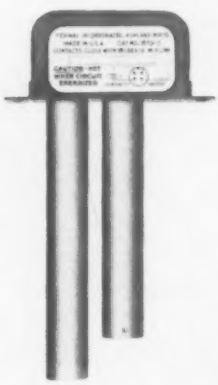


Flow Detector

Fenwal Inc., Ashland, Mass. The Detect-A-Flo is designed to sense and respond to changes or stoppages in the flow of air. Air-flow response is in the range 1,000–50,000 lb/hr/ft² (4–180 ft/sec for standard air). Operation is based on the thermostatic principle, depending on the amount of heat conducted away from the heat source by flowing air. Contact action is controlled by an expanding leg. Sensitivity is 0.25 ft/sec at low flows and 1 ft/sec at higher flows. (P-25)

Electrophoresis Unit

Microchemical Specialties Co., 1834 University Ave., Berkeley 3, Calif. This paper electrophoresis unit is designed for separation, identification and quantitative determination in complex systems such as mixtures of amino acids, lipids, steroids, carbohydrates and proteins. Up to ten analyses can

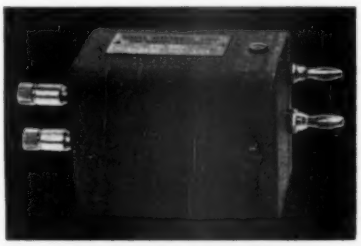
be made simultaneously. Buffer cells and tray for supporting filter paper are made of clear plastic. Different length trays can be used depending on length of paper. One stainless steel and one carbon rod are used as electrodes in the buffer cells. (P-26)

Power Meter

Polarad Electronics Corp., 100 Metropolitan Ave., Brooklyn 11, N. Y. This power meter measures rms power over the frequency range of d-c through X-band without the use of frequency-limited bolometer mounts. The instrument is completely self-contained, employing a single power probe for all frequencies. The meter is claimed to withstand 150% overload. Two power scales are available, 0–20 mw and 0–100 mw. The power range may be extended through the use of directional couplers, fixed pads or variable attenuators. (P-27)

Vacuum Gage

National Research Corp., 70 Memorial Dr., Cambridge 42, Mass. The model 516 Pirani vacuum gage operates in the range 1.0–0.001 mm Hg (1,000–1 micron). A low-impedance power rectifier eliminates voltage adjustments during operation. Outgassing circuitry on the pressure-range selector switch permits outgassing at any pressure without danger to the filament. Gage cords up to 100 ft long may be used. (P-28)



Line-Bridging Transformer

Sierra Electronic Corp., 1050 Brittan Ave., San Carlos 2, Calif. The model 122 line-bridging transformer, for converting voltmeters from single-ended to balance input, is compensated so readings are corrected for the transformer's insertion loss. The transformer is supplied for bridging measurements on systems of the following impedances: model 122A, 135 ohms; model 122B, 500 ohms; and model 122C, 600 ohms. Broad-band ferrite core unit operates flat within 0.5 db from 15 kc to 500 kc. (P-29)

Forged-Steel Valve

Hoppe Engineering Co., Inc., Greensboro, Ind. This forged-steel, welded-construction valve, smaller than comparable cast-steel valves, is said to be 85% lighter in weight; hydrostatic tests on 2-in. valves rate a cast-steel valve at 7,200 lb/in.^{2} and the forged-steel valve at 60,000 lb/in.^{2} Stainless-steel or Chrome Moly valves can be furnished in Class 5,000, 10,000, and 15,000, with screwed or flanged ends, in sizes $\frac{1}{2}$ to 10 in., inclusive. (P-30)

Inductors

Boonton Radio Corp., Boonton, N. J. The type 590-A line of inductors are useful for measuring r-f characteristics of condensers, resistors, and insulating

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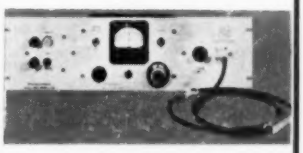

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materials over a range of 20 Mc to 230 Mc. The inductors consist of a high-Q coil mounted in a shield; spade lugs are provided for connection to Q-meter coil terminals. (P-31)

Signal Generator

Southwestern Industrial Electronics Co., 2831 Post Oak Rd., Houston 19, Texas. The model MB-1 battery-operated oscillator, available with calibrated output attenuator and level meter (Geophysical Microvolter) incorporated, can be used as a transducer simulator for field use, where it may be connected for test purposes in place of a vibration pickup. Both d-c and a-c signals are available, from 0.1 volt to 1 μv at output impedances of 10–500 ohms. Frequency range is 2–20,000 cycles/sec, calibrated within 2%; distortion is $<\frac{1}{2}\%$ in the audio range. (P-32)

Gas-Filling Unit

High Vacuum Equipment Corp., 349 Lincoln St., Hingham, Mass. This high-vacuum gas-filling unit is designed for evacuating air from mechanical and electrical assemblies, back filling with a partial pressure of an inert gas, and hermetically sealing the assemblies. Assemblies are placed in an electrically heated oven and individually connected with a built-in vacuum pumping system through water-cooled exhaust ports. In the closing phases of the exhaust cycle, the oven may be filled with

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helium. Should a leak be indicated, the faulty station can be isolated from the rest of the system. (P-33)

Ion-Exchange Resins

Bio-Rad Laboratories, 800 Delaware St., Berkeley 9, Calif. Dowex ion-exchange resins, supplied by Dow Chemical Co., is sized and purified by alternate acid, base, and organic-solvent cycles. Analysis of each batch covers moisture content, cross linkage, capacity, size distribution, and porosity. Resins now available, with various size distributions and cross linkages, include Dowex 50 (cation exchange) and Dowex 1, 2, and 3 (anion exchange). These styrene-type resins have capacities from 5.2 milliequivalents per dry gram for Dowex 50 to 3.0 for Dowex 2. (P-34)

INDUSTRY NOTES

▶**Correction: Radiation Detection Co.,** Station A, Box 155, Palo Alto, Calif., was formerly the Radiation Protection Div., Industrial Health and Hygiene Associates. The firm, whose business is film dosimetry, expects to have a new film-badge holder in production early in March.

▶**Technical Measurement Corp.,** Box 1947, New Haven, Conn., has purchased the assets of Utting Assoc., Inc., of Newton, Mass. George R. Utting has been appointed chief engineer of Technical Measurement. Instruments formerly manufactured by Utting are available from Technical Measurement.

LITERATURE AVAILABLE

Power resistors. Bulletin P-2 gives specifications and applications of types PW-7 and PW-10 resistors. *International Resistance Co., 401 N. Broad St., Philadelphia 8, Pa.* (L-1)

Polyethylene laboratory ware. Folder includes funnels, bottles, tubing, carboys. *E. Machlett & Son, 220 E. 23rd St., New York 10, N. Y.* (L-2)

Recording equipment. Catalog describes data-recording equipment, accessories, and supplies. *Edin Co., Inc., 207 Main St., Worcester, Mass.* (L-3)

Nucleonic equipment. Catalog describes detecting devices; counter-tube shields and accessories; protective, transporting and handling equipment;

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and timing devices. *El-Tronics, Inc., Fifth and Noble Sts., Philadelphia 23, Pa.* (L-4)

Complex plane analyzer. Bulletin describes theory of operation of 250-A analyzer. *Technology Instrument Corp., 531 Main St., Acton, Mass.* (L-5)

Hydraulic controls. Bulletin 25 covers operation, characteristics of ¼-in., solenoid-controlled, 4-way valves. *Pantex Mfg. Corp., Pawtucket, R. I.* (L-6)

Properties of gold. This booklet is a reprint of "Analysis of Gold and Gold Alloy Solutions" by E. A. Parker. *Technic, Inc., 39 Snow St., Providence 1, R. I.* (L-7)

Electric heat pump. Bulletin describes air-conditioning system. *Westinghouse Air Conditioning Div., Dept. T-557, 200 Readville St., Hyde Park, Boston 36, Mass.* (L-8)

Organic compounds. "Tales from the Alembic" humorously describes histories of some organic chemicals. *Eastman Organic Chemicals Div., Distillation Products Industries, Rochester 3, N. Y.* (L-9)

Electric meters. Brochure A-4 RCS describes volt-ohm-milliammeters and volt-ohm-microammeters. *Simpson Electric Co., 5200 W. Kinzie St., Chicago 44, Ill.* (L-10)

Valve installations. Brochure contains instructions on proper installation of line-blind valves; instructions can be applied to gate, globe, and plug valves. *Hamer Oil Tool Co., 2919 Gardenia Ave., Long Beach 6, Calif.* (L-11)

Pressure gages. Catalog gives information on gages, accessories, and gage engineering. *Manning, Maxwell & Moore, Inc., Stratford, Conn.* (L-12)

Liquid-level indicators. Bulletin S-68 describes indicator systems using ultrasonic pulses. *Bogue Electric Mfg. Co., 52 Iowa Ave., Paterson, N. J.* (L-13)

Light-weight pipe. Bulletin 507 gives applications and specifications of 4–30 in. lockseam spiral-weld pipe and fittings. *Naylor Pipe Co., 1230 E. 92nd St., Chicago 19, Ill.* (L-14)

Power supplies. Five supplies for voltage regulation are described in bulletin. *Allied Eng. Div., Allied International Inc., Connecticut and Richards Aves., South Norwalk, Conn.* (L-15)

Magnetic recording. Pamphlet on "Airfloating" describes method of magnetic recording applicable to auto-

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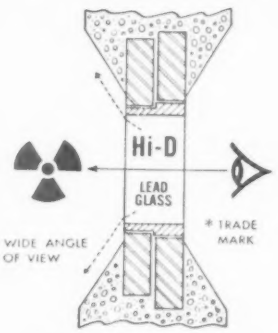

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matic computing equipment. *Logistics Research, Inc., 141 S. Pacific, Redondo Beach, Calif.* (L-16)

Vacuum pump care. Bulletin 755 gives tips on installing, operating, and maintaining vacuum systems. *F. J. Stokes Machine Co., 5500 Tabor Rd., Philadelphia 20, Pa.* (L-17)

Liquid pumps. This booklet provides selection guide and index to centrifugal and turbine-type pumps. *Aurora Pump Co., Aurora, Ill.* (L-18)

Phase-shift measurement. Laboratory Report No. 8 contains the article "Measuring Phase Shift through a Computing Magnetic Amplifier Using the Type 7000-A Primary Phase Standard." *Technology Instrument Corp., 531 Main St., Acton, Mass.* (L-19)

Refractory. Bulletin 226 describes refractory for sintering, annealing, melting, brazing, and other heat-treating applications. *Western Gold & Platinum Works, 589 Bryant St., San Francisco 7, Calif.* (L-20)

Laboratory ovens. Bulletin FS-230 describes uniformly heated ovens for 35–200° C. *Fischer Scientific Co., 717 Forbes St., Pittsburgh 19, Pa.* (L-21)

Process-control instruments. Catalog 2 includes flow meters, recorders, pressure regulators, and sight-flow indicators. *Fischer & Porter Co., 924 Jacksonville Rd., Hatboro, Pa.* (L-22)

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SPECIFICATIONS Model 410

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RESOLVING TIME: 0.1 μsec.
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OUTPUT:
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POWER REQUIREMENTS: 105-125 volts, 50-60 cycles, approximately 175 watts.
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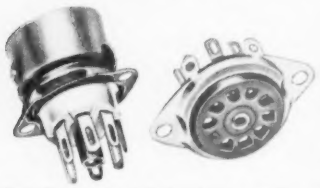

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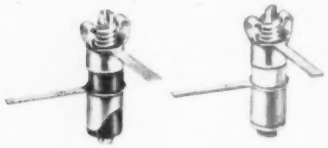

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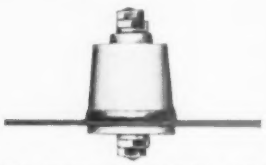

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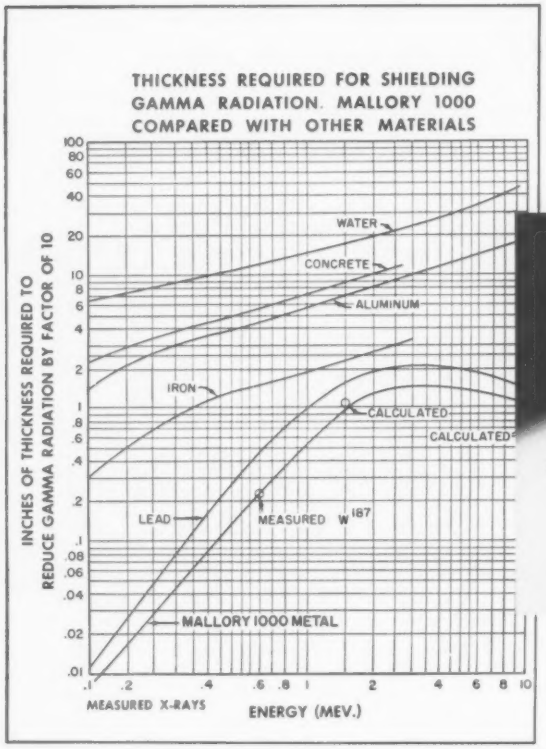

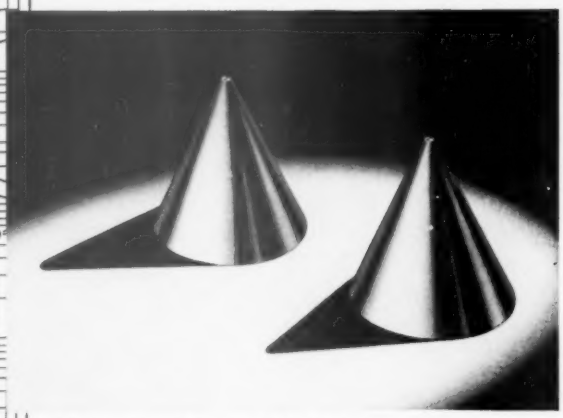

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